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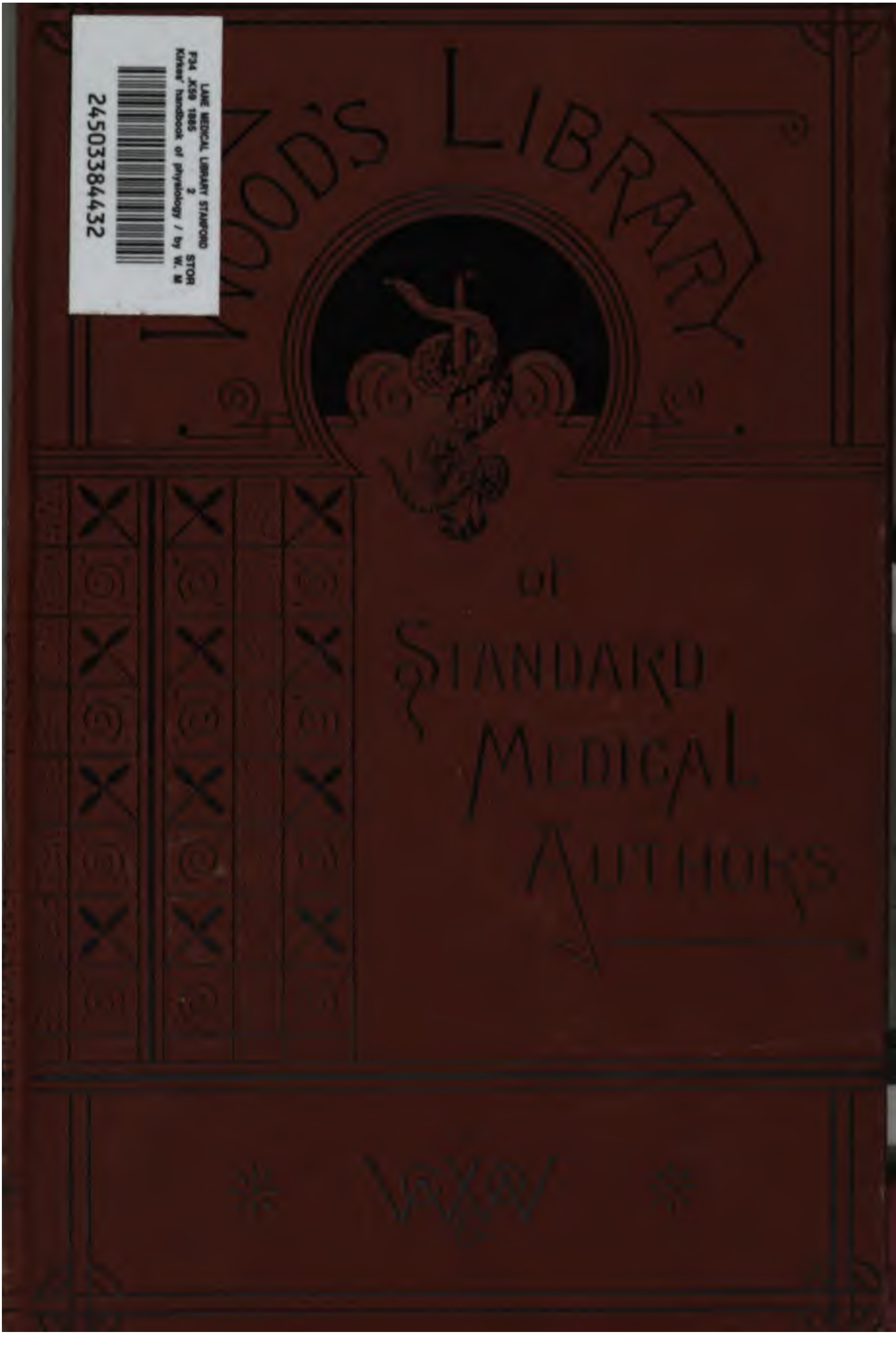

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HAND-BOOK

OF

PHYSIOLOGY

BY

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CHAPTER XIV.

THE VASCULAR GLANDS.

THE materials separated from the blood by the ordinary process of secretion in glands, are always discharged from the organ in which they are formed, and are either straightway expelled from the body, or if they are again received into the blood, it is only after they have been altered from their original condition, as in the cases of the saliva and bile. There appears, however, to be a modification of the process of secretion, in which certain materials are abstracted from the blood, undergo some change, and are added to the lymph or restored to the blood, without being previously discharged from the secreting organ, or made use of for any secondary purpose. The bodies in which this modified form of secretion takes place, are usually described as vascular glands, or glands without ducts, and include the *spleen*, the *thymus* and *thyroid* glands, the *supra-renal capsules*, the *pineal* gland and *pituitary* body, the *tonsils*. The solitary and agminate glands (Peyer's) of the intestine, and lymph-glands in general, also closely resemble them; indeed, both in structure and function, the vascular glands bear a close relation, on the one hand, to the true secreting glands, and on the other, to the lymphatic glands. The evidence in favor of the view that these organs exercise a function analogous to that of secreting glands, has been chiefly obtained from investigations into their structure, which have shown that most of the glands without ducts contain the same essential structures as the secreting glands, except the ducts.

THE SPLEEN.

The Spleen is the largest of the so-called ductless glands; it is situated to the left of the stomach, between it and the diaphragm. It is of a deep red color, of a variable shape, generally oval, somewhat concavo-convex. Vessels enter and leave the spleen at the inner side (hilus).

Structure.—The spleen is covered externally almost completely by a serous coat derived from the peritoneum, while within this is the proper fibrous coat or capsule of the organ. The latter, composed of connective tissue, with a large preponderance of elastic fibres, and a certain proportion of unstriated muscular tissue, forms the immediate investment of the spleen. Prolonged from its inner surface are fibrous processes or *trabeculæ*, containing much unstriated muscle, which enter the interior of the organ, and, dividing and anastomosing in all parts, form a kind of supporting framework or *stroma*, in the interstices of which the proper substance of the spleen (*spleen-pulp*) is contained (Fig. 254). At the hilus of the spleen, the blood-vessels, nerves, and lymphatics enter, and the fibrous coat is prolonged into the spleen-substance in the form of investing sheaths for the arteries and veins, which sheaths again are continuous with the *trabeculæ* before referred to.

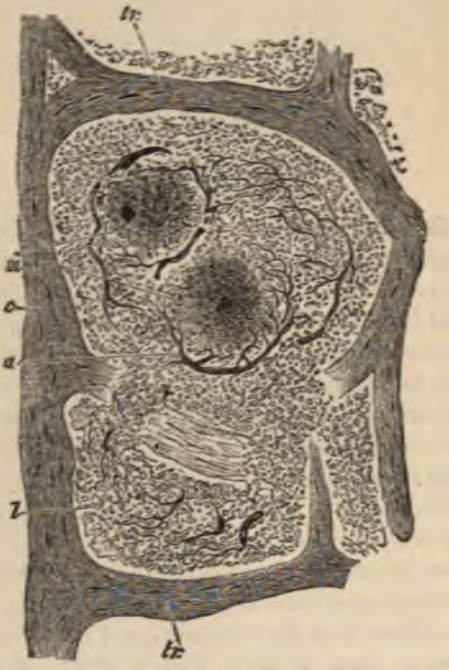


FIG. 254.—Section of dog's spleen injected: *c*, capsule; *tr*, trabeculæ; *m*, two Malpighian bodies with numerous small arteries and capillaries; *a*, artery; *l*, lymphoid tissue, consisting of closely-packed lymphoid cells supported by very delicate retiform tissue; a light space unoccupied by cells is seen all round the trabeculæ, which corresponds to the "lymph path" lymphatic glands. (Schofield.)

The *spleen-pulp*, which is a dark red or reddish-brown color, is composed chiefly of cells, imbedded in a matrix of fibres formed of the branching of large flattened nucleated endotheloid cells. The spaces of the network only partially occupied by cells form a freely communicating system. Of the cells some are granular corpuscles resembling the lymph corpuscles, more or less connected with the cells of the meshwork, both in general appearance and in being able to perform amœboid movements; others are red blood-corpuscles of normal appearance or variously changed; while there are also large cells containing either a pigment allied to the coloring matter of the blood, or rounded corpuscles like red blood-cells.

The splenic artery, after entering the spleen by its concave surface, divides and subdivides, with but little anastomosis between its branches; at the same time its branches are sheathed by the prolongations of fibrous coat, which they, so to speak, carry into the spleen with them. The arteries send off branches into the spleen-pulp which end in capillaries, and these either communicate, as in other parts of the body, with the radicles of the veins, or end in lacunar spaces in the spleen-pulp, from which veins arise (Gray).

The walls of the smaller veins are more or less incomplete, and readily allow lymphoid corpuscles to be swept into the blood-current. "The blood traverses the network of the pulp, and interstices of the lymphoid cells contained in the latter, in the same manner as the water of a river finds its way among the pebbles of its bed: the blood from the arterial capillaries is emptied into a system of intermediate passages, which are directly bounded by the cells and fibres of the network of the pulp, and from which the smallest venous radicles with their cribriform walls take origin" (Frey). The veins are large and very distensible: the whole tissue of the spleen is highly vascular, and becomes readily engorged with blood: the amount of distension is, however, limited by the fibrous and muscular tissue of its capsule and trabeculæ, which forms an investment and support for the pulpy mass within.

On the face of a section of the spleen can be usually seen readily with the naked eye, minute, scattered rounded or oval whitish spots, mostly from $\frac{1}{30}$ to $\frac{1}{60}$ inch in diameter. These are the *Malpighian corpuscles* of the spleen, and are situated on the sheaths of the minute splenic arteries, of which, indeed, they may be said to be outgrowths (Fig. 254). For while the sheaths of the larger arteries are constructed of ordinary connective tissue, this has become modified where it forms an investment for the smaller vessels, so as to be composed of adenoid tissue, with abundance of corpuscles, like lymph-corpuscles, contained in its meshes, and the Malpighian corpuscles are but small outgrowths of this *cytogenous* or cell-bearing connective tissue. They are composed of cylindrical masses of corpuscles, intersected in all parts by a delicate fibrillar tissue, which though it invests the Malpighian bodies, does not form a complete capsule. Blood-capillaries traverse the Malpighian corpuscles and form a plexus in their interior. The structure of a Malpighian corpuscle of the spleen is, therefore, very similar to that of lymphatic-gland substance.

Functions.—With respect to the office of the spleen, we have the following data. (1.) The large size which it gradually acquires toward the termination of the digestive process, and the great increase observed about this period in the amount of the finely-granular albuminous plasma within its parenchyma, and the subsequent gradual decrease of this material, seem to indicate that this organ is concerned in elaborating the albuminous materials of food, and for a time storing them up, to be gradually introduced into the blood, according to the demands of the general system.

(2.) It seems probable that the spleen, like the lymphatic glands, is engaged in the formation of blood-corpuscles. For it is quite certain, that the blood of the splenic vein contains an unusually large amount of white corpuscles; and in the disease termed leucocythæmia, in which the pale corpuscles of the blood are remarkably increased in number, there is almost always found an hypertrophied state of the spleen or of the lymphatic glands. In Kölliker's opinion, the development of colorless and also colored corpuscles of the blood is one of the essential functions of the spleen, into the veins of which the new-formed corpuscles pass, and are thus conveyed into the general current of the circulation.

(3.) There is reason to believe, that in the spleen many of the red corpuscles of the blood, those probably which have discharged their office and are worn out, undergo disintegration; for in the colored portions of the spleen-pulp an abundance of such corpuscles, in various stages of degeneration, are found, while the red corpuscles in the splenic venous blood are said to be relatively diminished. This process appears to be as follows. The blood-corpuscles, becoming smaller and darker, collect together in roundish heaps, which may remain in this condition, or become each surrounded by a cell-wall. The cells thus produced may contain from one to twenty blood-corpuscles in their interior. These corpuscles become smaller and smaller; exchange their red for a golden yellow, brown, or black color; and at length, are converted into pigment-granules, which by degrees become paler and paler, until all color is lost. The corpuscles undergo these changes whether the heaps of them are enveloped by a cell-wall or not.

(4.) From the almost constant presence of uric acid, as well as of the nitrogenous bodies, xanthin, hypoxanthin, and leucin, in the spleen, some nitrogenous metabolism may be fairly inferred to occur in it.

(5.) Besides these, its supposed direct offices, the spleen is believed to fulfil some purpose in regard to the portal circulation, with which it is in close connection. From the readiness with which it admits of being distended, and from the fact that it is generally small while gastric digestion is going on, and enlarges when that act is concluded, it is supposed to act as a kind of vascular reservoir, or diverticulum to the portal system, or more particularly to the vessels of the stomach. That it may serve such a purpose is also made probable by the enlargement which it undergoes in certain affections of the heart and liver, attended with obstruction to the passage of blood through the latter organ, and by its diminution when the congestion of the portal system is relieved by discharges from the bowels, or by the effusion of blood into the stomach. This mechanical influence on the circulation, however, can hardly be supposed to be more than a very subordinate function.

It is only necessary to mention that Schiff believes that the spleen manufactures a substance without which the pancreatic secretion cannot act upon proteids, so that when the spleen is removed the digestive action of the pancreas is stopped.

Influence of the Nervous System upon the Spleen.—When the spleen is enlarged after digestion, its enlargement is probably due to two causes, (1) a relaxation of the muscular tissue which forms so large a part of its framework; (2) a dilatation of the vessels. Both these phenomena are doubtless under control of the nervous system. It has been found by experiment that when the splenic nerves are cut the spleen enlarges, and that contraction can be brought about (1) by stimulation of the spinal cord (or of the divided nerves); (2) reflexly by stimulation of the central stumps of certain divided nerves, *e.g.*, vagus and sciatic; (3) by local stimulation by an electric current; (4) the exhibition of quinine and some other drugs. It has been shown by means of a modification of the plethysmograph (Roy), that the spleen undergoes rhythmical contractions and dilatations, due no doubt to the contraction and relaxation of the muscular tissue in its capsule and trabeculæ. The gland also shows the rhythmical alteration of the general blood pressure, but to a less extent than the kidney.

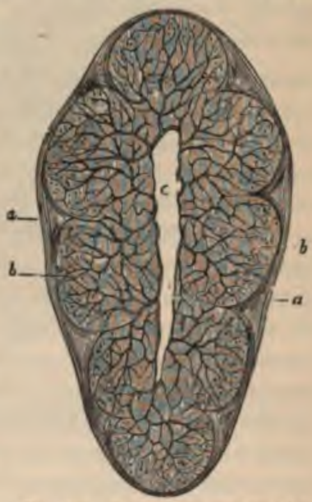


FIG. 255.—Transverse section of a lobule of an injected infantile thymus gland. *a*, capsule of connective tissue surrounding the lobule; *b*, membrane of the glandular vesicles; *c*, cavity of the lobule, from which the larger blood-vessels are seen to extend toward and ramify in the spheroidal masses of the lobule. × 30. (Kölliker.)

THE THYMUS.

This gland must be looked upon as a temporary organ, as it attains its greatest size early after birth, and after the second year gradually diminishes, until in adult life hardly a vestige remains. At its greatest development it is a long narrow body, situated in the front of the chest behind the sternum and partly in the lower part of the neck. It is of a reddish or greyish color, distinctly lobulated.

Structure.—The gland is surrounded by a fibrous capsule which sends in processes, forming trabeculæ, which divide the gland into lobes, and carry the blood and lymph-vessels. The large trabeculæ branch into small ones, which divide the lobes into lobules. The gland is encased in a fold of the pleura. The lobules are further subdivided into follicles by fine connective tissue. A follicle (Fig. 256) is more or less polyhedral in shape, and consists of cortical and medullary portions, the structure of both being of adenoid tissue, but in the medullary portion the matrix is coarser, and is not so filled up with lymphoid corpuscles as in the cortex. The adenoid tissue of the cortex, and to a less marked extent in the medulla, consists of two kinds of tissue, one with small meshes formed of fine fibres with thickened nodal points, and the other enclosed within the first, composed of branched connective-tissue corpuscles (Watney). Scattered in the adenoid tissue of the medulla are the *concentric corpuscles of Hassall*, which are protoplasmic masses of various sizes, consisting of a central nucleated granular centre, surrounded by flattened nucleated endothelial cells. In the reticulum, especially of the medulla, are large transparent giant cells. In the thymus of the dog and of other animals are to be found cysts, probably derived from the concentric corpuscles, some of which are lined with ciliated epithelium, and others with short columnar cells. Hæmoglobin is found in the thymus of all animals, either in these cysts, or in cells near to or of the concentric corpuscles. In the lymph issuing from the thymus are found cells containing colored blood-corpuscles and hæmoglobin granules, and in the lymphatics of the thymus there are more colorless cells than in the lymphatics of the neck. In the blood of the thymic vein, there appears sometimes to be an increase in the colorless corpuscles and also masses of granular matter (corpuscles of Zimmermann) (Watney). The arteries radiate from the centre of the gland. Lymph sinuses may be seen occasionally surrounding a greater or smaller portion of the periphery of the follicles (Klein). The nerves are very minute.

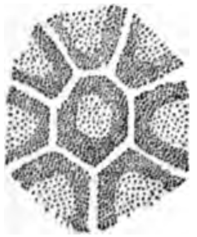


Fig. 256.—From a horizontal section through superficial part of the thymus of a calf, slightly magnified. Showing in the centre a follicle of polygonal shape with similarly shaped follicles round it. (Klein and Noble Smith.)

Function.—The thymus appears to take part in producing colored corpuscles, both from the large corpuscles containing hæmoglobin, and also indirectly from the colorless corpuscles (Watney). Respecting the function of the gland in the hybernating animals, in which it exists throughout life; as each successive period of hibernation approaches, the thymus greatly enlarges and becomes laden with fat, which accumulates in it and in fat-glands connected with it, in even larger proportions than it does in the ordinary seats of adipose tissue. Hence it appears to serve for the storing up of materials which, being re-absorbed in inactivity of the hibernating period, may maintain the respiration and the temperature of the body in the reduced state to which they fall during that time.

THE THYROID.

The Thyroid gland is situated in the neck. It consists of two lobes, one on each side of the trachea extending upward to the thyroid cartilage, covering its inferior cornu and part of its body; these lobes are connected across the middle line by a middle lobe or isthmus. The thyroid is covered by the muscles of the neck. It is highly vascular, and varies in size in different individuals.

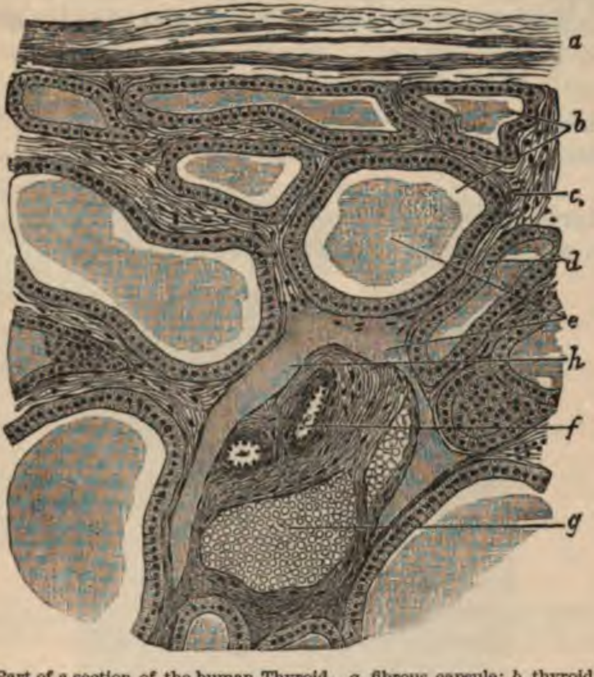


FIG. 257.—Part of a section of the human Thyroid. *a*, fibrous capsule; *b*, thyroid vesicles filled with, *e*, colloid substance; *c*, supporting fibrous tissue; *d*, short columnar cells lining vesicles; *f*, arteries; *g*, veins filled with blood; *h*, lymphatic vessel filled with colloid substance. (S. K. Alcock.)

Structure.—The gland is encased in a thin transparent layer of dense areolar tissue, free from fat, containing elastic fibres. This capsule sends in strong fibrous trabeculæ, which enclose the thyroid *vesicles*—which are rounded or oblong irregular sacs, consisting of a wall of thin hyaline membrane lined by a single layer of low cylindrical or cubical cells. These vesicles are filled with a coagulable fluid or transparent colloid material. The colloid substance increases with age, and the cavities appear to coalesce. In the interstitial connective tissue is a round meshed capillary plexus and a large number of lymphatics. The nerves adhere closely to the vessels.

In the vesicles there are in addition to the yellowish glassy colloid material, epithelium cells, colorless blood corpuscles, and also colored corpuscles undergoing disintegration.

Function.—There is little known definitely about the function of the thyroid body. It, however, produces the colloid material of the vesicles, which is carried off by the lymphatics and discharged into the blood, and so may contribute its share to the elaboration of that fluid. The destruction of red blood-corpuscles is also supposed to go on in the gland.

SUPRA-RENAL CAPSULES OR ADRENALS.

These are two flattened, more or less triangular or cocked-hat shaped bodies, resting by their lower border upon the upper border of the kidneys.

Structure.—The gland is surrounded by an outer sheath of connective tissue, which sometimes consists of two layers, sending in exceedingly fine prolongations forming the framework of the gland. The gland tissue proper consists of an outside firmer cortical portion, and an inside soft dark medullary portion. (1.) The *cortical portion* is divided into (Fig. 258 b) an external narrow layer of small rounded or oval spaces, the *zona glomerulosa,* made by the fibrous trabeculæ, containing multinucleated

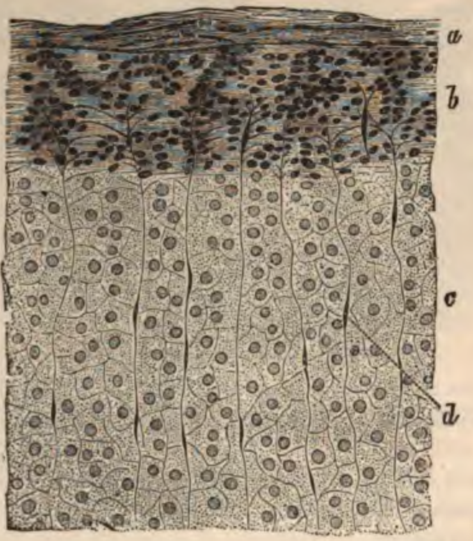


FIG. 258.—Vertical section through part of the cortical portion of supra-renal of guinea-pig. *a*, capsule; *b*, zona glomerulosa; *c*, zona fasciculata; *d*, connective tissue supporting the columns of the cells of the latter, and also indicating the position of the blood-vessels. (S. K. Alcock.)

masses of protoplasm, the differentiation of which into distinct cells cannot be made out. (*b*) A layer of cells arranged radially, the *zona fasciculata* (*c*). The substance of this layer is broken up into cylinders, each of which is surrounded by the connective-tissue framework. The cylinders thus produced are of three kinds—one containing an opaque, resistant, highly refracting mass (probably of a fatty nature); frequently a large number of nuclei are present; the individual cells can only be made out with difficulty. The second variety of cylinders is of a brownish color, and contains finely granular cells, in which are fat globules. The third variety consists of grey cylinders, containing a number of cells whose nuclei are filled with a large number of fat granules. The third layer of the cortical portion is the *zona reticularis* (not shown in Fig. 258). This layer is apparently formed by the breaking up of the cylinders, the elements being dispersed and isolated. The cells are finely granular, and have no deposit of fat in their interior; but in some specimens fat may be present, as well as certain large yellow granules, which may be called pigment granules.

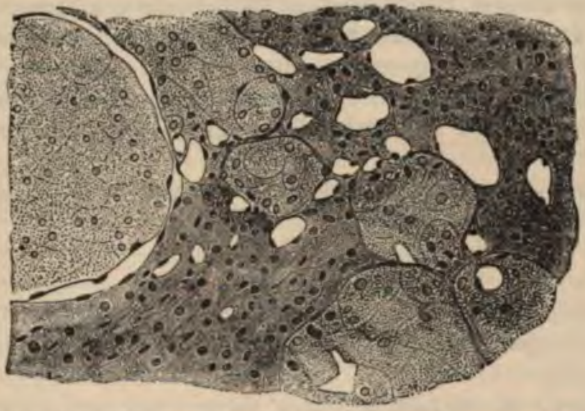


FIG. 259.—Section through a portion of the medullary part of the supra-renal of guinea-pig. The vessels are very numerous, and the fibrous stroma more distinct than in the cortex, and is moreover reticulated. The cells are irregular and larger, clean, and free from oil globules. (S. K. Alcock.)

(2.) The *medullary substance* consists of a coarse rounded or irregular meshwork of fibrous tissue, in the alveoli of which are masses of multinucleated protoplasm (Fig. 259); numerous blood-vessels; and an abundance of nervous elements. The cells are very irregular in shape and size, poor in fat, and occasionally branched; the nerves run through the cortical substance, and anastomose over the medullary portion.

Function.—Of the function of the supra-renal bodies nothing can be definitely stated, but they are in all probability connected with the lymphatic system.

Addison's Disease.—The collection of large numbers of cases in which the supra-renal capsules have been diseased, has demonstrated the very close relation subsisting between disease of those organs and brown discoloration of the skin (Addison's disease); but the explanation of this relation is still involved in obscurity, and consequently does not aid much in determining the functions of the supra-renal capsules.

PITUITARY BODY.

This body is a small reddish-grey mass, occupying the sella turcica of the sphenoid bone.

Structure.—It consists of two lobes—a small posterior one, consisting of nervous tissue; an anterior larger one, resembling the thyroid in structure. A canal lined with flattened or with ciliated epithelium, passes through the anterior lobe; it is connected with the infundibulum. The gland spaces are oval, nearly round at the periphery, spherical toward the centre of the organ; they are filled with nucleated cells of various sizes and shapes not unlike ganglion cells, collected together into rounded masses, filling the vesicles, and contained in a semi-fluid granular substance. The vesicles are enclosed by connective tissue rich in capillaries.

Function.—Nothing is known of the function of the pituitary body.

PINEAL GLAND.

This gland, which is a small reddish body, is placed beneath the back part of the corpus callosum, and rests upon the corpora quadrigemina (Fig. 327, *g*).

Structure.—It contains a central cavity lined with ciliated epithelium. The gland substance proper is divisible into—(1.) An outer cortical layer, analogous in structure to the anterior lobe of the pituitary body; and (2) An inner central layer, wholly nervous. The cortical layer consists of a number of closed follicles, containing (*a*) cells of variable shape, rounded, elongated, or stellate; (*b*) fusiform cells. There is also present a gritty matter (*acervulus cerebri*), consisting of round particles aggregated into small masses. The central substance consists of white and grey matter. The blood-vessels are small, and form a very delicate capillary plexus.

Function.—Of this there is nothing known.

FUNCTIONS OF THE VASCULAR GLANDS IN GENERAL.

The opinion that the vascular glands serve for the higher organization of the blood, is supported by their being all especially active in the discharge of their functions during fœtal life and childhood, when, for the development and growth of the body, the most abundant supply of highly organized blood is necessary. The bulk of the thymus gland, in proportion to that of the body, appears to bear almost a direct proportion to the activity of the body's development and growth, and when, at the period of puberty, the development of the body may be said to be complete, the gland wastes, and finally disappears. The thyroid gland and supra-renal capsules, also, though they probably never cease to discharge some amount of function, yet are proportionally much smaller in childhood than in fœtal life and infancy; and with the years advancing to the adult period, they diminish yet more in proportionate size and apparent activity of function. The spleen more nearly retains its proportionate size, and enlarges nearly as the whole body does.

The vascular glands seem not essential to life, at least not in the adult. The thymus wastes and disappears: no signs of illness attend some of the diseases which wholly destroy the structure of the thyroid gland; and the spleen has been often removed in animals, and in a few instances in men, without any evident ill-consequence. It is possible that, in such cases, some compensation for the loss of one of the organs may be afforded by an increased activity of function in those that remain.

Although the functions of all the vascular glands may be similar, in so far as they may all alike serve for the elaboration and maintenance of the blood, yet each of them probably discharges a peculiar office, in relation either to the whole economy, or to that of some other organ. Respecting the special office of the thyroid gland, nothing reasonable can be suggested; nor is there any certain evidence concerning that of the supra-renal capsules. Bergman believed that they formed part of the sympathetic nervous system from the richness of their nervous supply. Kölliker states that he is inclined to look upon the two parts as functionally distinct, the cortical part belonging to the blood vascular system, and the medullary to the nervous system.

CHAPTER XV.

CAUSES AND PHENOMENA OF MOTION.

In the animal body, motion is produced in these several ways: (1.) The oscillatory or vibratory movement of *Cilia*. (2.) *Amœboid* and certain *Molecular* movements. (3.) The contraction of *Muscular fibre*.

I. Ciliary Motion.

Ciliary, which is closely allied to amœboid and muscular motion (p. 8, Vol. I.), consists in the incessant vibration of fine, pellucid processes, about $\frac{1}{5000}$ of an inch long, termed *cilia* (Figs. 260, 261,) situated on the free extremities of the cells of epithelium covering certain surfaces of the body.

The distribution and structure of ciliary epithelium and the microscopic appearances of cilia in motion have been already described (pp. 25, 26, Vol. I.).

Ciliary motion is alike independent of the will, of the direct influence of the nervous system, and of muscular contraction. It continues for several hours after death or removal from the body, provided the portion of tissue under examination be kept moist. Its independence of the nervous system is shown also in its occurrence in the lowest invertebrate animals apparently unprovided with anything analogous to a nervous system, in its persistence in animals killed by prussic acid, by narcotic or other poisons, and after the direct application of narcotics to the ciliary sur-

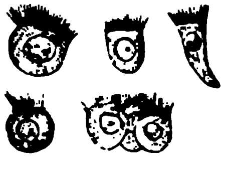


Fig. 260.

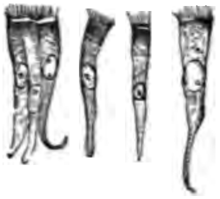


Fig. 261.

Fig. 260.—Spheroidal ciliated cells from the mouth of the frog: magnified 300 diameters. (Sharpey.)

Fig. 261.—Columnar ciliated cells from the human nasal membrane: magnified 300 diameters. (Sharpey.)

face, or the discharge of a Leyden jar, or of a galvanic shock through it. The vapor of chloroform arrests the motion; but it is renewed on the discontinuance of the application (Lister). The movement ceases in an atmosphere deprived of oxygen, but is revived on the admission of this gas. Carbonic acid stops the movement. The contact of various substances will stop the motion altogether; but this seems to depend chiefly on destruction of the delicate substance of which the cilia are composed.

Nature of Ciliary Action.—Little or nothing is known with certainty regarding the nature of ciliary action. It is a special manifestation of a similar property to that by which the other motions of animals are effected, namely, by what we term *vital contractility* (Sharpey). The fact of the more evident movements of the larger animals being effected by a structure apparently different from that of cilia, is no argument against such a supposition. For, if we consider the matter, it will be plain that our prejudices against admitting a relationship to exist between the two structures, muscles and cilia, rests on no definite ground; and for the simple reason, that we know so little of the manner of production of movement in either case. The mere difference of structure is not an argument in point; neither is the presence or absence of nerves. For in the fœtus the heart begins to pulsate when it consists of a mass of embryonic cells, and long before either muscular or nervous tissue has been differentiated. The movements of both muscles and cilia are manifestations of *energy*, by certain special structures, which we call respectively muscles and cilia. We know nothing more about the means by which the manifestation is effected by one of these structures than by the other: and the mere fact that one has nerves and the other has not, is no more argument against cilia having what we call a vital power of contraction, than the presence or absence of stripes from voluntary or involuntary muscles respectively, is an argument for or against the contraction of one of them being vital and the other not so.

As a special subdivision of ciliary action may be mentioned the motion of spermatozoa (Fig. 403), which may be regarded as cells with a single cilium.

II. AMŒBOID MOTION.

The remarkable movements observed in colorless blood corpuscles, connective-tissue corpuscles, and many other cells (p. 8, Vol. I.), must be regarded as depending on a kind of contraction of portions of their mass very similar to muscular contraction.

There is certainly an analogy between the spherical form assumed by a colorless blood-corpuscle on electric stimulation and the condition known as tetanus in muscles.

III. MUSCULAR MOTION.

Varieties of Muscular Tissue.—There are two chief kinds of muscular tissue: (1.) the *plain* or *non-striated*, and (2.) the *striated*, and they are distinguished by structural peculiarities and mode of action. The striped form of muscular fibre is sometimes called *voluntary* muscle, because all muscles under the direct control of the will are constructed of it. The plain or unstriped variety is often termed *involuntary*, because it alone is found in the greater number of the muscles over which the will has no power.

(1.) PLAIN OR UNSTRIPED MUSCLE.

Distribution.—Involuntary muscle forms the proper muscular coats (1.) of the digestive canal from the middle of the œsophagus to the internal sphincter ani; (2.) of the ureters and urinary bladder; (3.) the trachea and bronchi; (4.) the ducts of glands; (5.) the gall-bladder; (6.) the vesiculæ seminales; (7.) the pregnant uterus; (8.) of blood-vessels and lymphatics; (9.) the iris, and some other parts. This form of tissue also enters (10.) largely into the composition of the tunica dartos, and is the principal cause of the wrinkling and contraction of the scrotum on exposure to cold. Unstriped muscular tissue occurs largely also (11.) in the cutis (p. 335, Vol. I.), being especially abundant in the interspaces between the bases of the papillæ. Hence when it contracts under the influence of cold, fear, electricity, or any other stimulus, the papillæ are made unusually prominent, and give rise to the peculiar roughness of the skin termed *cutis anserina*, or goose skin. It occurs also in the superficial portion of the cutis, in all parts where hairs occur, in the form of flattened roundish bundles, which lie alongside the hair-follicles and sebaceous glands. They pass obliquely from without inward, embrace the sebaceous glands, and are attached to the hair-follicles near their base (Fig. 228).

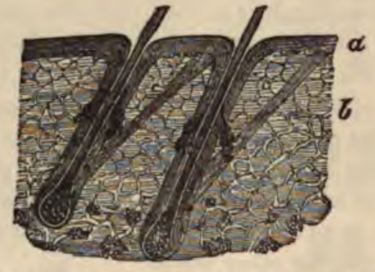


FIG. 262.—Vertical section through the scalp with two hair-sacs; *a*. epidermis; *b*, cutis; *c*, muscles of the hair-follicles. (Kölliker.)

Structure.—The non-striated muscles are made up of elongated, spindle-shaped, nucleated, *fibre cells* (Fig. 263), which in their perfect form are flat, from about $\frac{1}{4500}$ to $\frac{1}{3500}$ of an inch broad, and $\frac{1}{600}$ to $\frac{1}{300}$ of an inch in length,—very clear, granular, and brittle, so that when they break they often have abruptly rounded or square extremities. Each *muscle cell* consists of a fine sheath, probably elastic; of a central bundle of fibrils representing the contractile substance; and of an oblong nucleus which includes within a membrane a fine network anastomosing at the poles of the nucleus with the contractile fibrils. The ends of fibres are usually single, sometimes divided. Between the fibres is an albuminous cementing material (endomysium) in which are found connective-tissue corpuscles, and a few fibres. The *perimysium* is the fibrous connective tissue surrounding and separating the bundles of muscle cells.

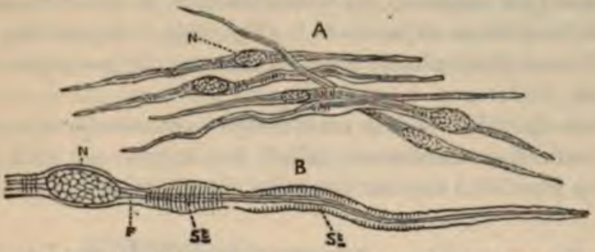


FIG. 263.—A, unstriped muscle cells from mesentery of newt, sheath with transverse marking faintly seen. × 180. B, from similar preparation, showing each muscle cell consists of a central bundle of fibrils (contractile part) connected with the intranuclear network and a sheath with annular thickenings. The cells show varicosities due to local contraction, and on these the annular thickenings are most marked. × 450. (Klein and Noble Smith.)

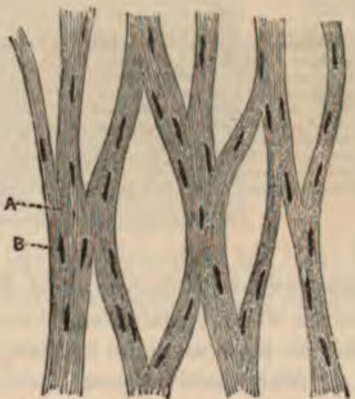


FIG. 264.—Plexus of bundles of unstriped muscle cells of the pulmonary pleura of the guinea-pig. × 180. (Klein and Noble Smith.)

(2.) STRIATED OR STRIPED MUSCLE.

Distribution.—The striated muscles include the whole class of *voluntary* muscles, the *heart*, and those muscles neither completely voluntary nor involuntary, which form part of the walls of the pharynx, and exist in many other parts of the body, as the internal ear, urethra, etc.

Structure.—All these muscles are composed of larger or smaller bundles of muscular fibres called *fasciculi*, enclosed in coverings of fibro-cellular tissue (*perimysium*), by which each is at once connected with and isolated from those adjacent to it (Fig. 265). Supporting the fibres contained in each fasciculus is a scanty amount of fine connective tissue *endomysium*.

Each muscular fibre is thus constructed:—Externally is a fine, transparent, structureless membrane, called the *sarcolemma* (Fig. 266, A), which in the form of a tubular investing sheath forms the outer wall of the fibre, and is filled up by the contractile material of which the fibre is chiefly composed. Sometimes, from its comparative toughness, the sarcolemma will remain untorn, when by extension the contained part can be broken (Fig. 269), and its presence is in this way best demonstrated. The fibres, which are cylindriform or prismatic, with an average diameter of about $\frac{1}{500}$ of an inch, are of a pale yellow color, and apparently marked by fine striæ, which pass transversely round them, in slightly curved or wholly parallel lines. Each fibre is found to consist of broad dim bands of highly refractive substance representing the contractile portion of the muscle fibre—the *contractile discs* (Fig. 267, A, *c*)—alternating with narrow bright bands of a less refractive substance—the *interstitial discs* (Fig. 267, A, *i*). After hardening, each contractile disc becomes longitudinally striated, the thin oblong rods thus formed being the *sarcous elements* of Bowman. The sarcous elements are not the optical units, since each consists of minute doubly-refracting elements—the *disdiaclasts*

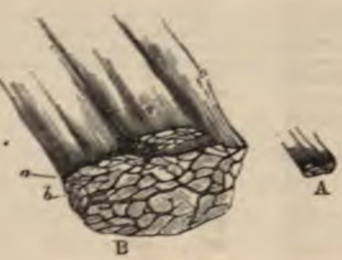


FIG. 265.

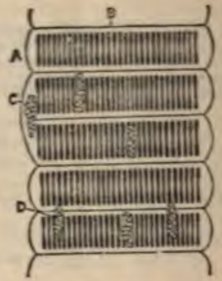


FIG. 266.

FIG. 265.—A small portion of muscle natural size, consisting of larger and smaller fasciculi, seen in a transverse section, and the same magnified 5 diameters. (Sharpey.)

FIG. 266.—Part of a striped muscle-fibre of a water-beetle (hydrophilus) prepared with absolute alcohol. A, sarcolemma; B, Krause's membrane. Owing to contraction during hardening, the sarcolemma shows regular bulgings. Above and below Krause's membrane are seen the transparent "lateral discs." The chief mass of a muscular compartment is occupied by the contractile disc composed of sarcous elements. The substance of the individual sarcous elements has collected more at the extremity than in the centre: hence this latter is more transparent. The optical effect of this is that the contractile disc appears to possess a "median disc" (Disc of Hensen). Several nuclei of muscle corpuscles, C and D, are shown, and in them a minute network. × 300. (Klein and Noble Smith.)

of Brücke. When seen in transverse section the contractile discs appear to be subdivided by clear lines into polygonal areas, *Cohnheim's fields* (Fig. 271), each corresponding to one sarcous element prism. The clear lines are due to a transparent interstitial fluid substance pressed out of the sarcous elements when they coagulate. There is still some doubt regarding the nature of the fibrils. Each of them appears to be composed of a single row of minute dark quadrangular particles, called *sarcous elements*, which are separated from each other by a bright space formed of a pellucid substance continuous with them. Sharpey believes that, even in a fibril so constituted, the ultimate anatomical element of the fibre has not been isolated. He believes that each fibril with quadrangular sarcous elements is composed of a number of other fibrils still finer, so that the sarcous element of an ultimate fibril would be not quadrangular, but as a streak. In either case the appearance of striation in the whole fibre would be produced by the arrangement, side by side, of the dark and light portions respectively of the fibrils (Fig. 267, B, *d*).

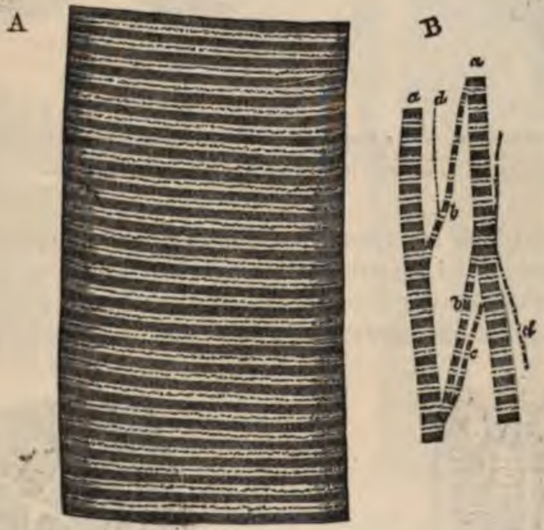


FIG. 267.—A. Portion of a medium-sized human muscular fibre. × 800. B. Separated bundles of fibrils equally magnified; *a*, *a*, larger, and *b*, *b*, smaller collections; *c*, still smaller; *d*, *d*, the smallest which could be detached, possibly representing a single series of sarcous elements. (Sharpey.)

A fine streak can usually be discerned passing across the interstitial disc between the sarcous elements: this streak is termed Krause's membrane: it is continuous at each end with the sarcolemma investing the muscular fibre (Fig. 266, B).

Thus the space enclosed by the sarcolemma is divided into a series of compartments by the transverse partitions known as Krause's membranes; these compartments being occupied by the true muscle substance. On each side (above and below) of Krause's membrane is a bright border (lateral disc). In the centre of the dark zone of sarcous elements a lighter band can sometimes be dimly discerned: this is termed the *middle disc of Hensen* (see Fig. 266, A).

In some fibres, chiefly those from insects, each lateral disc contains a row of bright granules forming the *granular layer* of Flögel. The fibres contain nuclei, which are roundish ovoid, or spindle-shaped in different animals. These nuclei are situated close to the sarcolemma, their long axes being parallel to the fibres which contain them. Each nucleus is composed of a uniform network of fibrils, and is embedded in a thin, more or less branched film of protoplasm. The nucleus and protoplasm together form the muscle cell or *muscle corpuscle* of Max Schultze.

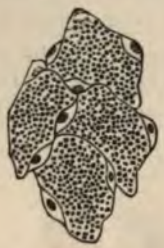


FIG. 268.

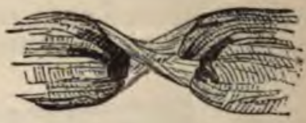


FIG. 269.

FIG. 268.—Transverse section of a muscle-fibre of water-beetle (hydrophilus pisceus), showing the position of the muscle nuclei. (Walter Pye.)

FIG. 269.—Muscular fibre torn across; the sarcolemma still connecting the two parts of the fibre. (Todd and Bowman.)

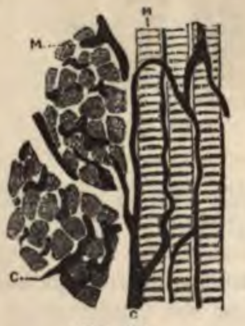


FIG. 270.

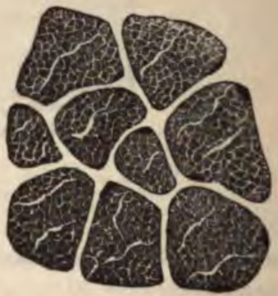


FIG. 271.

FIG. 270.—Section through the muscular substance of the tongue, with capillaries injected, their meshes running parallel to the fibres. Three muscular fibres are seen running longitudinally, and two bundles of fibres in transverse section. × 150. (Klein and Noble Smith.)

FIG. 271.—Transverse section through muscular fibres of human tongue: the fibres appear in transverse section of different sizes owing to their being more or less spindle-shaped. The muscle-corpuscles are indicated by their deeply-stained nuclei situated at the inside of the sarcolemma. Each muscle-fibre shows the "Cohnheim's fields," that is the sarcous elements in transverse section separated by clear (apparently linear) interstitial substance. × 450. (Klein and Noble Smith.)

The sarcous elements and Krause's membranes are doubly refracting, the rest of the fibre singly refracting (Brücke).

According to Schäfer, the granules, which have been mentioned on either side of Krause's membrane, are little knobs attached to the ends of "muscle-rods;" and these muscle-rods, knobbed at each end and imbedded in a homogeneous protoplasmic ground-substance, form the substance of the muscles. This view, however, of the structure of muscle requires further confirmation before it can be accepted.

Although each muscular fibre may be considered to be formed of a number of longitudinal fibrils, arranged side by side, it is also true that they are not naturally separate from each other, there being *lateral* cohesion, if not fusion, of each sarcous element with those around and in contact with it; so that it happens that there is a tendency for a fibre to split, not only into separate fibrils, but also occasionally into plates or discs, each of which is composed of sarcous elements laterally adherent one to another.

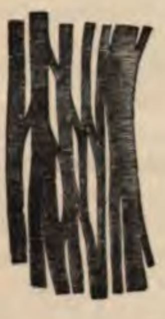


FIG. 272.

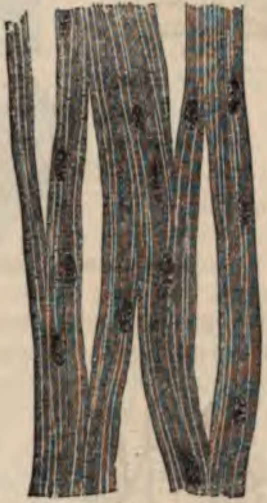


FIG. 273.

FIG. 272.—Muscular fibres from the heart, magnified, showing their cross-striæ, divisions, and junctions. (Kölliker.)

FIG. 273.—Network of muscular fibres (striated) from the heart of a pig. The nuclei of the muscle-corpuscles are well shown. × 450. (Klein and Noble Smith.)

Muscular Fibres of the Heart (Figs. 272 and 273) form the chief, though not the only exception to the rule, that involuntary muscles are constructed of *plain* fibres; but although striated and so far resembling those of the skeletal muscles, they present these distinctions:—Each muscular fibre is made up of elongated, nucleated, and branched cells, the nuclei or muscle-corpuscles being centrally placed in the fibre. The fibres are finer and less distinctly striated than those of the voluntary muscles; and no sarcolemma can be usually discerned.

Blood and Nerve Supply.—The voluntary muscles are freely supplied with blood-vessels; the capillaries form a network with oblong meshes around the fibres on the outside of the sarcolemma. No vessels penetrate the sarcolemma to enter the interior of the fibre (Fig. 270). Nerves also are supplied freely to muscles (pp. 76, 80, Vol. II.); the voluntary muscles receiving chiefly nerves from the cerebro-spinal system, and the unstriped muscles from the sympathetic or ganglionic system.

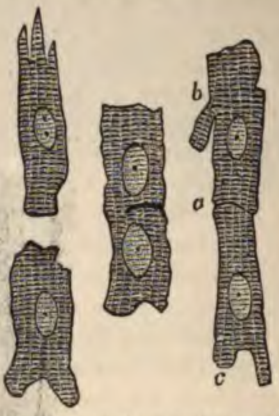


FIG. 274.—Muscular fibre cells from the heart. (E. A. Schäfer.)

Development.—(1.) *Unstriped.*—The cells of unstriped muscle are derived directly from embryonic cells, by an elongation of the cell, and its nucleus; the latter changing from a vascular to a rod shape.

(2.) *Striped.*—Formerly it was supposed that striated fibres are formed by the coalescence of several cells, but recently it has been proved, that each fibre is formed from a single cell, the process involving an enormous increase in size, a multiplication of the nucleus by fission, and a differentiation of the cell-contents (Remak, Wilson Fox). This view differs but little from that previously taken by Savory, that the muscular fibre is produced, not by multiplication of cells, but by arrangement of nuclei in a growing mass of protoplasm (answering to the cell in the theory just referred to), which becomes gradually differentiated so as to assume the characters of a fully developed muscular fibre.

Growth of Muscle.—The growth of muscles, both striated and non-striated, is the result of an increase both in the number and size of the individual elements.

In the pregnant uterus the fibre-cells may become enlarged to ten times their original length. In involution of the uterus after parturition the reverse changes occur, accompanied generally by some fatty infiltration of the tissue and degeneration of the fibres.

PHYSIOLOGY OF MUSCLE.

Muscle may exist in three different conditions: *rest*, *activity*, and *rigor*.

I. Rest.

Physical Condition.—During rest or inactivity a muscle has a slight but very perfect *elasticity;* it admits of being considerably stretched; but returns readily and completely to its normal length. In the living body the muscles are always *stretched* somewhat beyond their natural length, they are always in a condition of slight tension; an arrangement which enables the whole force of the contraction to be utilized in approximating the points of attachment. It is obvious that if the muscles were lax, the first part of the contraction till the muscle became tight would be wasted.

There is no doubt that even in a condition of rest *oxygen* is being *abstracted from the blood* and carbonic acid given out by a muscle; for the blood becomes venous in the transit, and since the muscles form by far the largest element in the composition of the body, chemical changes must be constantly going on in them as in other tissues and organs, although not necessarily accompanied by contraction. When cut out of the body such muscles retain their contractility longer in an atmosphere of oxygen than in an atmosphere of hydrogen or carbonic acid, and during life, an amount of oxygen is no doubt necessary to the manifestation of energy as well as for the metabolism going on in the resting condition.

Chemical composition.—The reaction of living muscle is *neutral* or *slightly alkaline.* The substance or muscle plasma which forms the contractile principal element in its composition undergoes coagulation when the muscle is removed from the body, and the process may be observed if the coagulation be delayed by cold. If the muscles of a frog be frozen, minced whilst in that condition, and reduced to a pulp by being rubbed up with a 1 per cent. solution of sodium chloride, the temperature of which must be very low, on filtration in the cold, a colorless, somewhat turbid filtrate separates with difficulty, which is muscle plasma. This fluid at the ordinary temperature of the air undergoes a coagulation or clotting, by which it is separated, as in the case of blood, into *muscle-serum* and *muscle-clot.* The latter, however, is not made up of fibrin but of *myosin,* which is a globulin (p. 328, Vol. II.). Myosin may also be obtained from dead muscle by subjecting it, after all the blood, fat, fibrous tissue, and substances soluble in water, have been removed, to a ten per cent. solution of sodium chloride, filtering and allowing the filtrate to drop into a large quantity of water; myosin separating out as a white flocculent precipitate. Obtained in either way, viz., from living or dead muscle, myosin is soluble in dilute saline solutions, and the solution undergoes coagulation at a lower temperature than serum-albumin or paraglobulin, viz., at 131°—140° F. (55°—60° C.). It is coagulated also by alcohol. It is dissolved and converted into acid-albumin by dilute acid, such as hydrochloric.

Muscle-serum is acid in reaction, contains serum-albumin and several other proteids as well as other bodies, among which are fats; free acids, especially sarco-lactic, formic, and acetic; glucose, glycogen and inosite; kreatin, hypoxanthin, or carnin, taurin, and other nitrogenous crystalline bodies; many salts, of which the chief is potassium phosphate; Carbonic acid, and lastly Hæmoglobin, on which the color of muscles partially depends. There are also traces of ferments, pepsin among others.

Electrical Condition; Natural muscle currents.—In muscles which have been removed from the body, it has been found that electrical currents can be demonstrated for some little time, passing from point to point on their surface; but as soon as the muscles die or enter into rigor mortis, these currents disappear. The method of demonstration usually employed is as follows: The frog's muscles are most convenient for experiment, and a muscle of regular shape, in which the fibres are parallel, is selected. The ends are cut off by clean vertical cuts, and the resulting piece of muscle is called a regular muscle prism. The muscle prism is insulated, and a pair of non-polarizable electrodes connected with a very delicate galvanometer are applied to various points of the prism, and by a deflection of the needle to a greater or less extent in one direction or another, the strength and direction of the currents in the piece of muscle can be estimated. It is necessary to use non-polarizable and not metallic electrodes in this experiment, as otherwise there is no certainty that the whole of the current observed is communicated from the muscle and is not derived from the metallic electrodes themselves in consequence of the action of the saline juices of the tissues upon them. The form of the non-polarizable electrodes is a modification of Du Bois Reymond's appa-

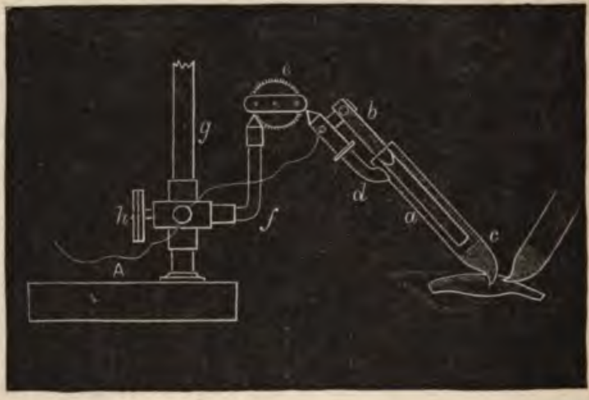


FIG. 275.—Diagram of Du Bois Reymond's non-polarizable electrodes. *a*, glass tube filled with a saturated solution of zinc sulphate, in the end, *c*, of which is china clay drawn out to a point; in the solution a well amalgamated zinc rod is immersed and connected by means of the wire which passes through A with the galvanometer. The remainder of the apparatus is simply for convenient application. The muscle to the end of the second electrode is to the right of the figure.

ratus (Fig. 275), which consists of a somewhat flattened glass cylinder *a*, drawn abruptly to a point and fitted to a socket capable of movement and attached to a stand A, so that it can be raised or lowered as required. The lower portion of the cylinder is filled with china clay moistened with saline solution, part of which projects through its drawn-out point, the rest of the cylinder is fitted with a saturated solution of zinc sulphate into which dips a well amalgamated piece of zinc which is connected by means of a wire with the galvanometer. In this way the zinc sulphate forms an homogeneous and non-polarizable conductor between the zinc and the china clay. A second electrode of the same kind is, of course, necessary.

In such a regular muscle prism the currents are found to be as follows:—

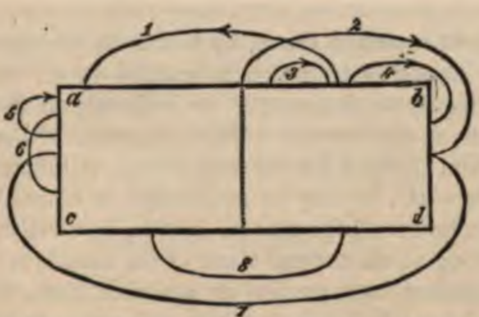


FIG. 276.—Diagram of the currents in a muscle prism. (Du Bois Reymond.)

If from a point on the surface a line—the equator—be drawn across the muscle prism equally dividing it, currents pass from this point to points away from it, which are weak if the points are near, and increase in strength as the points are further and further away from the equator; the strongest passing from the equator to a point representing the middle of the cut ends (Fig. 276, 2); currents also pass from points nearer the equator to those more remote (Fig. 276, 1, 3, 4), but not from points equally distant, or iso-electric points (Fig. 276, 6. 7, 8). The cut ends are always negative to the equator. These currents are constant for some time after removal of the muscle from the body, and in fact remain as long as the muscle retains its life. They are in all probability due to chemical change going on in the muscles.

The currents are diminished by fatigue and are increased by an increase of temperature within natural limits. If the uninjured tendon be used as the end of the muscle, and the muscle be examined without removal from the body, the currents are very feeble, but they are at once much increased by injuring the muscle, as by cutting off its tendon. The last observation appears to show that they are right who believe that the currents do not exist in muscles uninjured *in situ*, but that injury, either mechanical, chemical or thermal, will render the injured part electrically negative to other points on the muscle. In a frog's heart it has been shown, too, that no currents exist during its inactivity, but that as soon as it is injured in any way currents are developed, the injured part being negative to the rest of the muscle. The currents which have been above described are called either *natural muscle currents* or *currents of rest*, according as they are looked upon as always existing in muscle or as developed when a part of the muscle is subjected to injury; in either case, up to a certain point, it is agreed that the strength of the currents is in direct proportion to the injury.

II. Activity.

The property of muscular tissue, by which its peculiar functions are exercised, is its *contractility*, which is excited by all kinds of stimuli applied either directly to the muscles, or indirectly to them through the medium of their motor nerves. This property, although commonly brought into action through the nervous system, is inherent in the muscular tissue. For—(1). it may be manifested in a muscle which is isolated from the influence of the nervous system by division of the nerves supplying it, so long as the natural tissue of the muscle is duly nourished; and (2). it is manifest in a portion of muscular fibre, in which, under the microscope, no nerve-fibre can be traced. (3). Substances such as *urari*, which paralyze the nerve-endings in muscles, do not at all diminish the irritability of the muscle. (4). When a muscle is fatigued, a local stimulation is followed by a contraction of a small part of the fibre in the immediate vicinity without any regard to the distribution of nerve-fibres.

If the removal of nervous influence be long continued, as by division of the nerves supplying a muscle, or in cases of paralysis of long-standing, the irritability, *i.e.*, the power of both perceiving and responding to a stimulus, may be lost; but probably this is chiefly due to the impaired nutrition of the muscular tissue, which ensues through its inaction. The irritability of muscles is also of course soon lost, unless a supply of arterial blood to them is kept up. Thus, after ligature of the main arterial trunk of a limb, the power of moving the muscles is partially or wholly lost, until the collateral circulation is established; and when, in animals, the abdominal aorta is tied, the hind legs are rendered almost powerless.

The same fact may be readily shown by compressing the abdominal aorta in a rabbit for about 10 minutes; if the pressure be released and the animal be placed on the ground, it will work itself along with its front legs, while the hind legs sprawl helplessly behind. Gradually the muscles recover their power and become quite as efficient as before.

So. also, it is to the imperfect supply of arterial blood to the muscular tissue of the heart, that the cessation of the action of this organ in asphyxia is in some measure due.

Sensibility.—Besides the property of contractility, the muscles, especially the striated, possess sensibility by means of the sensory nerve-fibres distributed to them. The amount of common sensibility in muscles is not great; for they may be cut or pricked without giving rise to severe pain, at least in their healthy condition. But they have a peculiar sensibility, or at least a peculiar modification of common sensibility, which is shown in that their nerves can communicate to the mind an accurate knowledge of their states and positions when in action. By this sensibility, we are not only made conscious of the morbid sensations of fatigue and cramp in muscles, but acquire, through muscular action, a knowledge of the distance of bodies and their relation to each other, and are enabled to estimate and compare their weight and resistance by the effort of which we are conscious in measuring, moving, or raising them. Except with such knowledge of the position and state of each muscle, we could not tell how or when to move it for any required action; nor without such a sensation of effort could we maintain the muscles in contraction for any prolonged exertion.

MUSCULAR CONTRACTION.

The power which muscles possess of contraction may be called forth by stimuli of various kinds, viz., by Mechanical, Thermal, Chemical, and Electrical means, and these stimuli may also be applied directly to the muscle or indirectly to the nerve supplying it. There are distinct advantages, however, in applying the stimulus through the nerves, as it is more convenient, as well as more potent.

Mechanical stimuli, as by a blow, pinch, prick of the muscle or its nerve, will produce a contraction, repeated on the repetition of the stimulus; but if applied to the same point for a limited number of times only, as such stimuli will soon destroy the irritability of the preparation.

Thermal stimuli.—If a needle be heated and applied to a muscle or its nerve, the muscle will contract. A temperature of over 100° F. (37·8° C.) will cause the muscles of a frog to pass into a condition known as *heat rigor*.

Chemical stimuli.—A great variety of chemical substances will excite the contraction of muscles, some substances being more potent in irritating the muscle itself, and other substances having more effect upon the nerve. Of the former may be mentioned, dilute acids, salts of certain metals, *e.g.*, zinc, copper and iron; to the latter belong strong glycerin, strong acids, ammonia and bile salts in strong solution.

Electrical stimuli.—These are most frequently used as muscle stimuli, as the strength of the stimulus may be more conveniently regulated.

The kind of current employed may be, for the sake of clearness, treated of under two heads:—(1) *The continuous current,* and (2) *The induced current.* (1) The continuous current is supplied by a battery such as that of Daniell, by which an electrical current which varies but little in intensity is obtained. The battery (Fig. 277) consists of a positive plate of well-amalgamated zinc immersed in a porous cell, containing dilute sulphuric acid; and this cell is again contained within a larger copper vessel (forming the negative plate), containing besides a saturated solution of copper sulphate. The electrical current is made continuous by the use of the two fluids in the following manner. The action of the dilute sulphuric acid upon the zinc plate partly dissolves it and liberates hydrogen, and this gas passes through the porous vessel and decomposes the copper sulphate into copper and sulphuric acid. The former is deposited upon the copper plate and the latter passes through the porous vessel to renew the sulphuric acid which is being used up. The copper sulphate solution is renewed by spare crystals of the salt which are kept on a little shelf attached to the copper plate and slightly below the level of the solution in the vessel. The current of electricity supplied by this battery will continue without variation for a considerable time. Other continuous-current batteries such as Grove's may be used in place of Daniell's. The way in which the apparatus is arranged is to attach wires to the copper and zinc plates and to bring them to a key, which is a little apparatus for connecting the wires of a battery. One often employed is Du Bois Reymond's (Fig. 280, D); it consists of two pieces of brass about an inch long, in each of which are two holes for wires and binding screws to fix them tightly; these pieces of brass are fixed upon a vulcanite plate, to the under surface of which is a screw clamp by which it can be secured to the table. The interval between the pieces of brass can be bridged over by means of a third thinner piece of similar metal fixed by a screw to one of the brass pieces and capable of movement by a handle at right angles, so as to touch the other piece of brass. If the wires from the

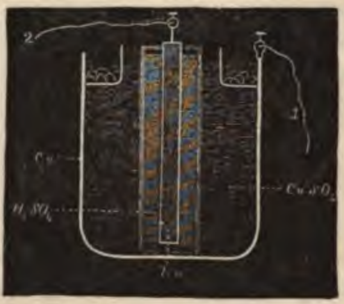


FIG. 277.—Diagram of a Daniell's Battery. (After Balfour Stewart.)

battery are brought to the inner binding screws, and the bridge be brought to connect them, the current passes across it and back to the battery. Wires are connected with the outer binding screws, and the other ends are approximated for about two inches, but, being covered except at their points, are insulated, the uncovered points are about an eighth of an inch apart. These wires are the *electrodes,* and the electrical stimulus is applied to the muscle, if they are placed behind its nerve and the connection between the two brass plates of the key be broken by depressing the handle of the bridge and so raising the connecting piece of metal. The key is then said to be opened. (2) *The induced current.*—An induced current is developed by means of an apparatus called an *induction coil,* and the one employed for physiological purposes is mostly the one (Fig. 278).

Wires from a battery are brought to the two binding screws *d′* and *d,* a key intervening. These binding screws are the ends of a coil of coarse covered wire *c,* called the primary coil. The ends of a coil of finer covered wire *g,* are attached to two binding screws to the left of the figure, one only of which is visible. This is the secondary coil and is capable of being moved nearer to *c* along a grooved and graduated scale. To the binding screws to the left of *g,* the wires of electrodes used to stimulate the muscle are attached. If the key in the circuit of wires from the battery to the primary coil (primary circuit) be closed, the current from the battery passes through the primary coil and across the key to the battery and continues to pass as long as the key continues closed. At the moment of closure of the key, at the exact instant of the completion of the primary circuit, an instantaneous current of electricity is induced in the secondary coil, *g,* if it be sufficiently near, and the nearer it is to *c,* the stronger is the current. The induced current is only momentary in duration and

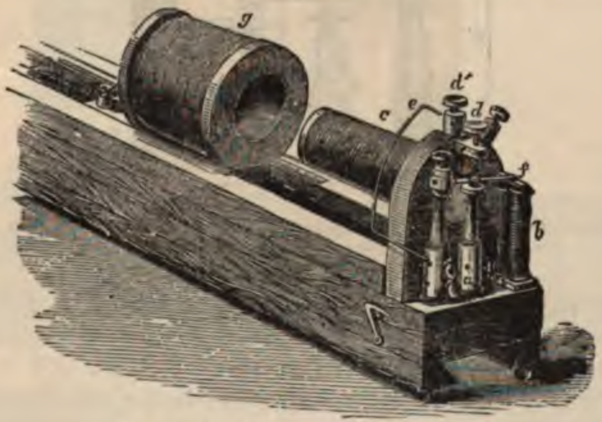


FIG. 278.—Du Bois Reymond's induction coil.

does not continue during the whole of the period when the primary circuit is complete. When, however, the primary current is broken by opening the key, a second, also momentary, current is induced in *g*. The former induced current is called the *making*, and the latter the *breaking* shock; the former is in the opposite to, and the latter in the same direction, as the primary current.

The induction coil may be used to produce a rapid series of shocks by means of another and accessory part of the apparatus at the right of the figure. If the wires from a battery are connected with the two pillars by the binding screws, one below *c*, and the other, *a*, the course of the current is indicated in Fig. 279, the direction being indicated by the arrows.

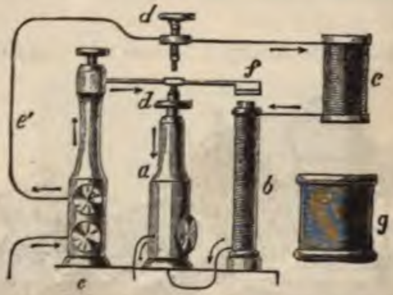


FIG. 279.—Diagram of the course of the current in the magnetic interrupter of Du Bois Reymond's induction coil. (Helmholz's modification.)

The current passes up the pillar from *e* and along the spring, if the end of *d'* be close to the spring, and the current passes to the primary coil *c*, and to wires covering two upright pillars of soft iron, from them to the pillar *a*, and out by the wires to the battery; in passing along the wire, *b*, the soft iron is converted into a magnet and so attracts the hammer, *f*, of the spring, breaks the connection of the spring with *d'* and so cuts off the current from the primary coil and also from the electro-magnet. As the pillars, *b*, are no longer magnetized the spring is released and the current passes in the first direction, and is in like manner interrupted. At each make and break of the primary current, currents corresponding are induced in the secondary coil. These currents are, as before, in an opposite direction, but are not equal in intensity, the break shock being greater. In order that the shocks should be about equal at the make and break, a wire (Fig. 279, *e'*) connects *e* and *d'*, and the screw *d'* is raised out of reach of the spring, and *d* is raised (as in Fig. 279), so that part of the current always passes through the primary coil and electro-magnet. When the spring touches *d*, the current in *b* is diminished, but never entirely withdrawn, and the primary current is altered in intensity at each contact of the spring with *d*, but never entirely broken.

RECORD OF MUSCULAR CONTRACTION UNDER STIMULI.

The muscles of the frog are those which can most conveniently be experimented with and their contractions recorded. The frog is pithed, that is to say its central nervous system is entirely destroyed by the insertion of a stout needle into the spinal cord and the parts above it. One of its lower extremities is used in the following manner. The large trunk of the sciatic nerve is dissected out at the back of the thigh, and a pair of electrodes is inserted behind it. The tendo-achillis is divided from its attachment to the os calcis, and a ligature is tightly tied round it. This tendon is part of the broad muscle of the thigh (gastrocnemius) which arises from above the condyles of the femur. The femur is now fixed to a board covered with cork, and the ligature attached to the tendon is tied to the upright of a piece of metal bent at right angles (Fig. 280, B), which is capable of movement about a pivot at its knee, the horizontal portion carrying a writing lever (myograph). When the muscle contracts the lever is raised. It is necessary to attach a small weight to the

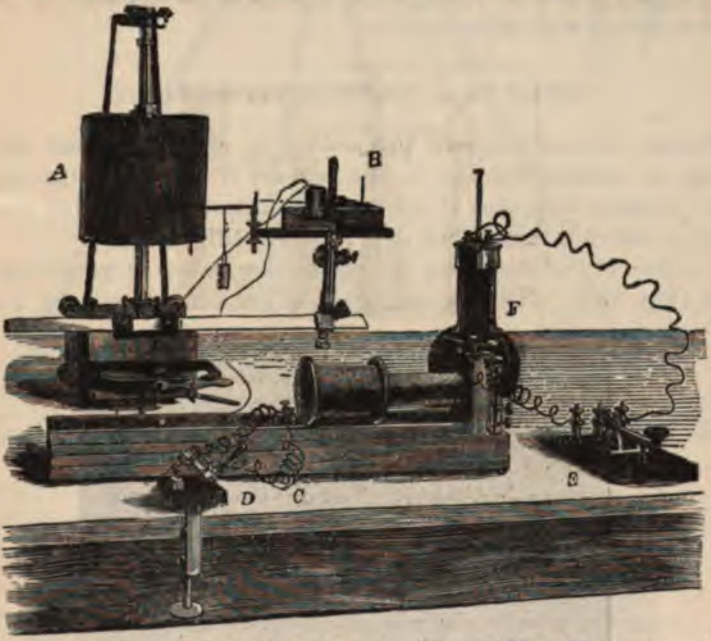


FIG. 280.—Arrangement of the apparatus necessary for recording muscle contractions with a revolving cylinder carrying smoked paper. A, revolving cylinder; B, the frog arranged upon a cork-covered board which is capable of being raised or lowered on the upright, which also can be moved along a solid triangular bar of metal attached to the base of the recording apparatus—the tendon of the gastrocnemius is attached to the writing lever properly weighted by a ligature. The electrodes from the secondary coil pass to the apparatus—being, for the sake of convenience, first of all brought to a key, D (Du Bois Reymond's); C, the induction coil; F, the battery (in this figure a bichromate one); E, the key (Morse's) in the primary circuit.

lever. In this arrangement the muscle is *in situ*, and the nerve disturbed from its relations as little as possible.

The muscle may, however, be detached from the body with the lower end of the femur from which it arises, and the nerve going to it may be taken away with it. The femur is divided at about the lower third. The bone is held in a firm clamp, the nerve is placed upon two electrodes connected with an induction apparatus, and the lower end of the muscle is connected by means of a ligature attached to its tendon with a lever which can write on a recording apparatus.

To prevent evaporation this so-called *nerve-muscle preparation* is placed under a glass shade, the air in which is kept moist by means of blotting paper saturated with saline solution.

EFFECT OF A SINGLE INDUCTION SHOCK.

Taking the nerve-muscle preparation in either of these ways, on closing or opening the key in the primary circuit we obtain and can record a contraction, and if we use the clockwork apparatus revolving rapidly, a curve is traced such as is shown in (Fig. 281).

Another way of recording the contraction is by the pendulum myograph (Fig. 282). Here the movement of the pendulum along a certain arc is substituted for the clockwork movement of the other apparatus. The pendulum carries a smoked glass plate upon which the writing lever of a myograph is made to mark. The opening or breaking shock is sent into the nerve-muscle preparation by the pendulum in its swing opening a key (Fig. 282, *C.*) in the primary circuit.

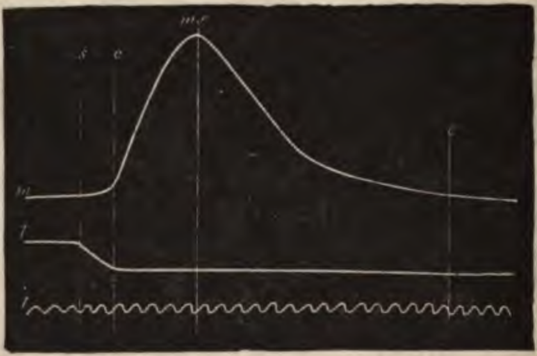


FIG. 281.—Muscle-curve obtained by the pendulum myograph. *s*, indicates the exact instant of the induction shock; *c*, commencement; and *m x*, the maximum elevation of lever; *t*, the line of a vibrating tuning-fork. (M. Foster.)

Single Muscle Contraction.—The tracings obtained in a manner above described and seen in Fig. 281, may be thus explained.

The upper line (*m*) represents the curve traced by the end of the lever after stimulation of the muscle by a single induction-shock: the middle line (l) is that described by the marking-lever, and indicates by a sudden drop the exact instant at which the induction-shock was given. The lower wavy line (t) is traced by a vibrating tuning-fork, and serves to measure precisely the intervals of time occupied in each part of the contraction.

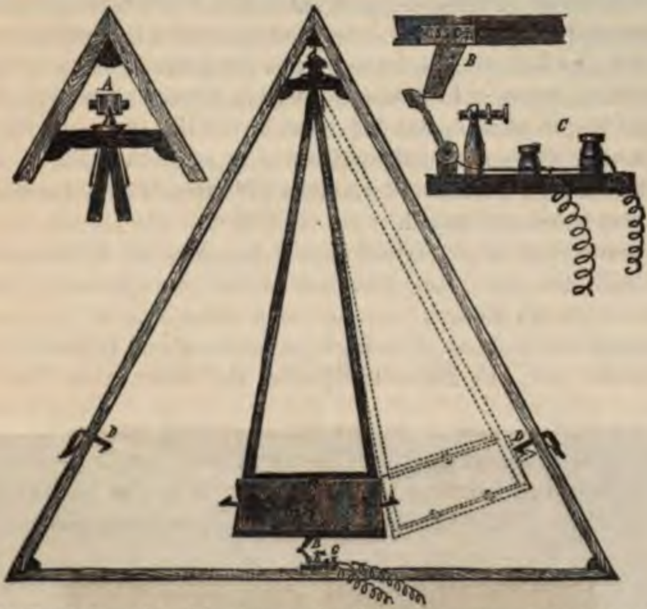


FIG. 282.—Simple form of pendulum myograph and accessory parts. *A*, pivot upon which pendulum swings; *B*, catch on lower end of myograph opening the key, *C*, in its swing; *D*, a spring-catch which retains myograph, as indicated by dotted lines, and on pressing down the handle of which the pendulum swings along the arc to *D* on the left of figure, and is caught by its spring.

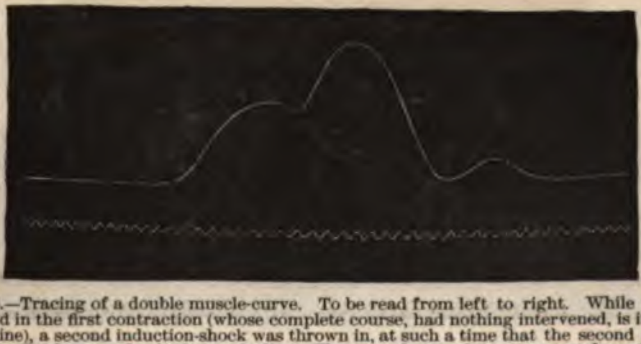


FIG. 283.—Tracing of a double muscle-curve. To be read from left to right. While the muscle was engaged in the first contraction (whose complete course, had nothing intervened, is indicated by the dotted line), a second induction-shock was thrown in, at such a time that the second contraction began just as the first was beginning to decline. The second curve is seen to start from the first, as does the first from the base line. (M. Foster.)

It will be observed that after the stimulus has been applied, as indicated by the vertical line s, there is an interval before the contraction commences, as indicated by the line *c*. This interval, termed the "*latent period*" (Helmholtz), when measured by the number of vibrations of the tuning-fork between the lines *s* and *c*, is found to be about $\frac{1}{100}$ sec.

The contraction progresses rapidly at first and afterward more slowly to the maximum (the point in the curve through which the line *mx* is drawn) which takes $\frac{4}{100}$ sec., and then the muscle elongates again as indicated by the descending curve, at first rapidly, afterward more slowly, till it attains its original length at the point indicated by the line *c′*, occupying $\frac{5}{100}$ sec.

The muscle curve obtained from the heart resembles that of unstriped muscles in the long duration of the effect of stimulation; the descending curve is very much prolonged.

The greater part of the latent period is taken up by changes in the muscle itself, the rest being occupied in the propagation of the shock along the nerve (M. Foster).

Tetanus.—If instead of a single induction-shock through the preparation we pass two, one immediately after the other, when the point of stimulation of the second one corresponds to the maximum of the first, a second curve (Fig. 283) will occur which will commence at the highest point of the first and will rise as high, so that the sum of the height of the two exactly equals twice the height of the first. If a third and a fourth shock be passed, a similar effect will ensue, and curves one above the other

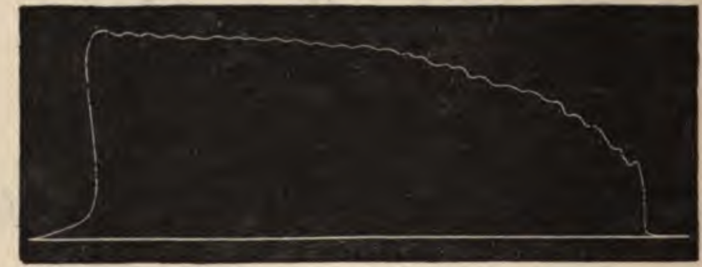


FIG. 284.—Curve of tetanus, obtained from the gastrocnemius of a frog, where the shocks were sent in from an induction coil, about sixteen times a second, by the interruption of the primary current by means of a vibrating spring, which dipped into a cup of mercury, and broke the primary current at each vibration.

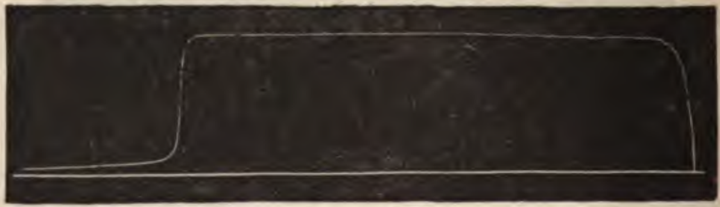


FIG. 285.—Curve of tetanus, from a series of very rapid shocks from a magnetic interrupter.

will be traced, the third being slightly less than the second, and the fourth than the third. If the shocks be repeated at short intervals, however, the lever after a time ceases to rise any further, and the contraction which has reached its maximum is maintained (Fig. 285), and the lever marks a straight line on the recording cylinder. This condition is called *tetanus of muscle.* The condition of "an ordinary tetanic muscular movement is essentially a vibratory movement, the apparently rigid and firm muscular mass is really the subject of a whole series of vibrations, a series namely of simple spasms; it will be readily understood why a tetanized muscle, like all other vibrating bodies, gives out a sound" (M. Foster).

If the stimuli are not quite so rapidly sent in the line of maximum contraction it becomes somewhat wavy, indicating a slight tendency of the muscles to relax during the intervals between the stimuli (Fig. 284).

Muscular Work.—We have seen (p. 124, Vol. I.) that *work* is estimated by multiplying the weight raised, by the height through which it has been lifted. It has been found that in order to obtain the maximum of work, a muscle must be moderately *loaded:* if the weight be increased beyond a certain point, the muscle becomes strained and raises the weight through so small a distance that less work is accomplished. If the load is still further increased the muscle is completely overtaxed, cannot raise the weight, and consequently does no work at all. Practical illustrations of these facts must be familiar to every one.

The power of a muscle is usually measured by the maximum weight which it will support without stretching. In man this is readily determined by weighting the body to such an extent that it can no longer be raised on tiptoe: thus the power of the calf-muscles is determined (Weber).

The power of a muscle thus estimated depends of course upon its cross-section. The power of a human muscle is from two to three times as great as a frog's muscle of the same sectional area.

Fatigue of Muscle.—A muscle becomes rapidly exhausted from repeated stimulation, and the more rapidly, the more quickly the induction-shocks succeed each other.

This is indicated by the diminished height of contraction in the accompanying diagrams (Fig. 286). It will be seen that the vertical lines, which indicate the extent of the muscular contraction, decrease in length from left to right. The line A B drawn along the tops of these lines is termed the "fatigue curve." It is usually a straight line.

In the first diagram the effects of a short rest are shown: there is a pause of three minutes, and when the muscle is again stimulated it contracts up to A′, but the recovery is only temporary, and the *fatigue curve,* after a few more contractions, becomes continuous with that before the rest.

In the second diagram is represented the effect of a stream of oxygenated blood. Here we have a sudden restoration of energy: the muscle in this case makes an entirely fresh start from A, and the new fatigue curve is parallel to, and never coincides with the old one.

A fatigued muscle has a much longer "latent period" than a fresh one. The slowness with which muscles respond to the will when fatigued must be familiar to every one.

In a muscle which is exhausted, stimulation only causes a contraction producing a local bulging near the point irritated. A similar effect may be produced in a fresh muscle by a sharp blow, as in striking the biceps smartly with the edge of the hand, when a hard muscular swelling is instantly formed.

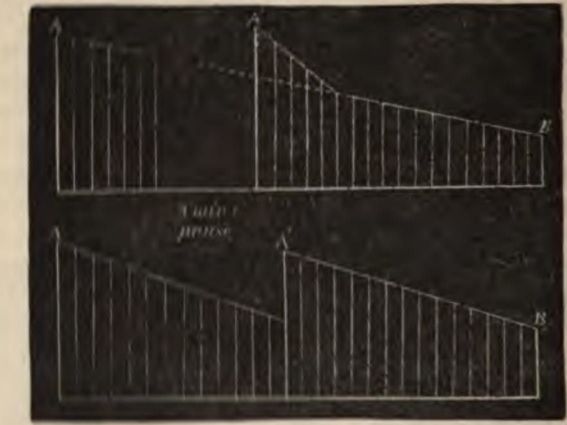


Fig. [illegible].—Fatigue muscle-curves. (Ray Lankester.)

Accompaniments of Muscular Contraction.—(1.) *Heat* is developed in the contraction of muscles. Becquerel and Breschet found, with the thermo-multiplier, about 1° Fahr. of heat produced by each forcible contraction of a man's biceps; and when the actions were long continued, the temperature of the muscle increased 2°. This estimate is probably high, as in the frog's muscle a considerable contraction has been found to produce an elevation of temperature equal on an average to less than $\frac{1}{5}$° C. It is not known whether this development of heat is due to chemical changes ensuing in the muscle, or to the friction of its fibres vigorously acting: in either case, we may refer to it a part of the heat developed in active exercise (p. 310, Vol. I.).

(2.) *Sound* is said to be produced when muscles contract forcibly, as mentioned above. Wollaston showed that this sound might be easily heard by placing the tip of the little finger in the ear, and then making some muscles contract, as those of the ball of the thumb, whose sound may be conducted to the ear through the substance of the hand and finger.

A low shaking or rumbling sound is heard, the height and loudness of the note being in direct proportion to the force and quickness of the muscular action, and to the number of fibres that act together, or, as it were, in time.

(3.) *Changes in shape.*—The *mode of contraction* in the transversely striated muscular tissue has been much disputed. The most probable account is, that the contraction is effected by an approximation of the constituent parts of the fibrils, which, at the instant of contraction, without any alteration in their general direction, become closer, flatter, and wider; a condition which is rendered evident by the approximation of the transverse striæ seen on the surface of the fasciculus, and by its increased breadth and thickness. The appearance of the zigzag lines into which it was supposed the fibres are thrown in contraction, is due to the relaxation of a fibre which has been recently contracted, and is not at once stretched again by some antagonist fibre, or whose extremities are kept close together by the contractions of other fibres. The contraction is therefore a simple, and, according to Ed. Weber, a uniform, simultaneous, and steady shortening of each fibre and its contents. What each fibril or fibre loses in length, it gains in thickness: the contraction is a change of form, not of size; it is, therefore, not attended with any diminution in bulk, from condensation of the tissue. This has been proved for entire muscles, by making a mass of muscle, or many fibres together, contract in a vessel full of water, with which a fine, perpendicular, graduated tube communicates. Any diminution of the bulk of the contracting muscle would be attended by a fall of fluid in the tube; but when the experiment is carefully performed, the level of the water in the tube remains the same, whether the muscle be contracted or not.

In thus shortening, muscles appear to swell up, becoming rounder, more prominent, harder, and apparently tougher. But this hardness of muscle in the state of contraction, is not due to increased firmness or condensation of the muscular tissue, but to the increased tension to which the fibres, as well as their tendons and other tissues, are subjected from the resistance ordinarily opposed to their contraction. When no resistance is offered, as when a muscle is cut off from its tendon, not only is no hardness perceived during contraction, but the muscular tissue is even softer, more extensile, and less elastic than in its ordinary uncontracted state.

(4.) *Chemical changes.*—(*a*) The reaction of the muscle which is normally alkaline or neutral becomes decidedly acid, from the development of sarcolactic acid. (*b*) The muscle gives out carbonic acid gas and takes up oxygen, the amount of the carbonic acid given out not appearing to be entirely dependent upon the oxygen taken in, and so doubtless in part arising upon some other source. (*c*) Certain imperfectly understood chemical changes occur, in all probability connected with (*a*) and (*b*).

Glycogen is diminished, and muscle sugar (inosite) appears; the extractives are increased.

(5.) *Electrical changes.*—When a muscle contracts the natural muscle current or currents of rest undergo a distinct diminution, which is due to the appearance in the actively contracting muscle of currents in an opposite direction to those existing in the muscle at rest. This causes a temporary deflection of the needle of a galvanometer in a direction opposite to the original current, and is called by some the *negative variation* of the muscle current, and by others a *current of action*.

Conditions of Contraction.—(*a*) The irritability of muscle is greatest at a certain mean temperature; (*b*) after a number of contractions a muscle gradually becomes exhausted; (*c*) the activity of muscles after a time disappears altogether when they are removed from the body or the arteries are tied; (*d*) oxygen is used up in muscular contraction, but a muscle will act for a time *in vacuo* or a gas which contains no oxygen: in this case it is of course using up the oxygen already in store (Hermann).

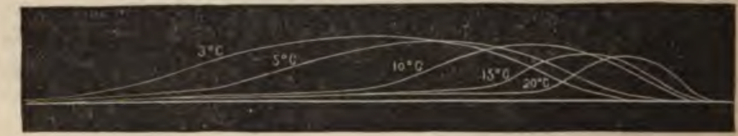


FIG. 287.—Muscle-curves from the gastrocnemius of a frog, illustrating effects of alterations in temperature.

Response to Stimuli.—The two kinds of fibres, the striped and unstriped, have characteristic differences in the mode in which they act on the application of the same stimulus; differences which may be ascribed in great part to their respective differences of structure, but to some degree, possibly, to their respective modes of connection with the nervous system. When irritation is applied directly to a muscle with striated fibres, or to the motor nerve supplying it, contraction of the part irritated, and of that only, ensues; and this contraction is instantaneous, and ceases on the instant of withdrawing the irritation. But when any part with unstriped muscular fibres, *e.g.*, the intestines or bladder, is irritated, the subsequent contraction ensues more slowly, extends beyond the part irritated, and, with alternating relaxation, continues for some time after the withdrawal of the irritation. The difference in the modes of contraction of the two kinds of muscular fibres may be particularly illustrated by the effects of the electro-magnetic stimulus. The rapidly succeeding shocks given by this means to the nerves of muscles excite in all the transversely-striated muscles a fixed state of tetanic contraction as previously described, which lasts as long as the stimulus is continued, and on its withdrawal instantly ceases; but in the muscles with smooth fibres they excite, if any movement, only one that ensues slowly, is comparatively slight, alternates with rest, and continues for a time after the stimulus is withdrawn.

In their mode of responding to these stimuli, all the skeletal muscles, or those with transverse striæ, are alike; but among those with plain or unstriped fibres there are many differences,—a fact which tends to confirm the opinion that their peculiarity depends as well on their connection with nerves and ganglia as on their own properties. The ureters and gall-bladder are the parts least excited by stimuli: they do not act at all till the stimulus has been long applied, and then contract feebly, and to a small extent. The contractions of the cæcum and stomach are quicker and wider-spread: still quicker those of the iris, and of the urinary bladder if it be not too full. The actions of the small and large intestines, of the vas deferens, and pregnant uterus, are yet more vivid, more regular, and more sustained; and they require no more stimulus than that of the air to excite them. The heart, on account, doubtless, of its striated muscle, is the quickest and most vigorous of all the muscles of organic life in contracting upon irritation, and appears in this, as in nearly all other respects, to be the connecting member of the two classes of muscles.

All the muscles retain their property of contracting under the influence of stimuli applied to them or to their nerves for some time after death, the period being longer in cold-blooded than in warm-blooded Vertebrata, and shorter in Birds than in Mammalia. It would seem as if the more active the respiratory process in the living animal, the shorter is the time of duration of the irritability in the muscles after death; and this is confirmed by the comparison of different species in the same order of Vertebrata. But the period during which this irritability lasts, is not the same in all persons, nor in all the muscles of the same persons. In a man it ceases, according to Nysten, in the following order:—first in the left ventricle, then in the intestines and stomach, the urinary bladder, right ventricle, œsophagus, iris; then in the voluntary muscles of the trunk, lower and upper extremities; lastly in the right and left auricle of the heart.

III. Rigor Mortis.

After the muscles of the dead body have lost their irritability or capability of being excited to contraction by the application of a stimulus, they spontaneously pass into a state of contraction, apparently identical with that which ensues during life. It affects all the muscles of the body; and, where external circumstances do not prevent it, commonly fixes the limbs in that which is their natural posture of equilibrium or rest. Hence, and from the simultaneous contraction of all the muscles of the trunk, is produced a general stiffening of the body, constituting the *rigor mortis* or *post-mortem rigidity*.

When this condition has set in, the muscle becomes acid in reaction (due to sarco-lactic acid), and gives off carbonic acid in great excess. Its volume is slightly diminished: the muscular fibres become shortened and opaque, and their substance has set firm. It comes on much more rapidly after muscular activity, and is hastened by warmth. It may be brought on, in muscles exposed for experiment, by the action of distilled water and many acids, also by freezing and thawing again.

Cause.—The immediate cause of rigor seems coagulation of the muscle plasma (Brücke, Kühne, Norris). We may distinguish three main stages.—(1.) Gradual coagulation. (2.) Contraction of coagulated muscle-clot (myosin) and squeezing out of muscle-serum. (3.) Putrefaction. After the first stage, restoration is possible through the circulation of arterial blood through the muscles, and even when the second stage has set in, vitality may be restored by dissolving the coagulum of the muscle in salt solution, and passing arterial blood through its vessels. In the third stage recovery is impossible.

Order of Occurrence.—The muscles are not affected simultaneously by *post-mortem* contraction. It affects the neck and lower jaw first; next, the upper extremities, extending from above downward; and lastly, reaches the lower limbs; in some rare instances only, it affects the lower extremities before, or simultaneously with, the upper extremities. It usually ceases in the order in which it began; first at the head, then in the upper extremities, and lastly in the lower extremities. It never commences earlier than ten minutes, and never later than seven hours, after death; and its duration is greater in proportion to the lateness of its accession. Heat is developed during the passage of a muscular fibre into the condition of rigor mortis.

Since rigidity does not ensue until muscles have lost the capacity of being excited by external stimuli, it follows that all circumstances which cause a speedy exhaustion of muscular irritability, induce an early occurrence of the rigidity, while conditions by which the disappearance of the irritability is delayed, are succeeded by a tardy onset of this rigidity. Hence its speedy occurrence, and equally speedy departure, in the bodies of persons exhausted by chronic diseases; and its tardy onset and long continuance after sudden death from acute diseases. In some cases of sudden death from lightning, violent injuries, or paroxysms of passion, rigor mortis has been said not to occur at all; but this is not always the case. It may, indeed, be doubted whether there is really a complete absence of the post-mortem rigidity in any such cases; for the experiments of Brown-Séquard make it probable that the rigidity may supervene immediately after death, and then pass away with such rapidity as to be scarcely observable.

Experiments.—Brown-Séquard took five rabbits, and killed them by removing their hearts. In the first, rigidity came on in 10 hours, and lasted 192 hours; in the second, which was feebly electrified, it commenced in 7 hours, and lasted 144; in the third, which was more strongly electrified, it came on in two, and lasted 72 hours; in the fourth, which was still more strongly electrified, it came on in one hour, and lasted 20; while, in the last rabbit, which was submitted to a powerful electro-galvanic current, the rigidity ensued in seven minutes after death, and passed away in 25 minutes. From this it appears that the more powerful the electric current, the sooner does the rigidity ensue, and the shorter is its duration; and as the lightning shock is so much more powerful than any ordinary electric discharge, the rigidity may ensue so early after death, and pass away so rapidly as to escape detection. The influence exercised upon the onset and duration of post-mortem rigidity by causes which exhaust the irritability of the muscles, was well illustrated in further experiments by the same physiologist, in which he found that the rigor mortis ensued far more rapidly, and lasted for a shorter period in those muscles which had been powerfully electrified just before death than those which had not been thus acted upon.

The occurrence of rigor mortis is not prevented by the previous existence of paralysis in a part, provided the paralysis has not been attended with very imperfect nutrition of the muscular tissue.

The rigidity affects the involuntary as well as the voluntary muscles, whether they be constructed of striped or unstriped fibres. The rigidity of involuntary muscles with striped fibres is shown in the contraction of the heart after death. The contraction of the muscles with unstriped fibres is shown by an experiment of Valentin, who found that if a graduated tube connected with a portion of intestine taken from a recently-killed animal, be filled with water, and tied at the opposite end, the water will in a few hours rise to a considerable height in the tube, owing to the contraction of the intestinal walls. It is still better shown in the arteries, of which all that have muscular coats contract after death, and thus present the roundness and cord-like feel of the arteries of a limb lately removed, or those of a body recently dead. Subsequently they relax, as do all the other muscles, and feel lax and flabby, and lie as if flattened, and with their walls nearly in contact.

ACTIONS OF THE VOLUNTARY MUSCLES.

The greater part of the voluntary muscles of the body act as sources of power for removing levers,—the latter consisting of the various bones to which the muscles are attached.

Examples of the three orders of levers in the Human Body.—All levers have been divided into three kinds, according to the relative position of the *power*, the *weight* to be removed, and the *axis of motion* or *fulcrum*. In a lever of the *first* kind the *power* is at one extremity of the lever, the *weight* at the other, and the *fulcrum* between the two. If the initial letters only of the *power, weight*, and *fulcrum* be used, the arrangement will stand thus:—P.F.W. A poker, as ordinarily used, or the bar in Fig. 288, may be cited as an example of this variety of lever; while, as an instance in which the bones of the human skeleton are used as a lever of the same kind, may be mentioned the act of raising the body from the stooping posture by means of the hamstring muscles attached to the tuberosity of the ischium (Fig. 288).

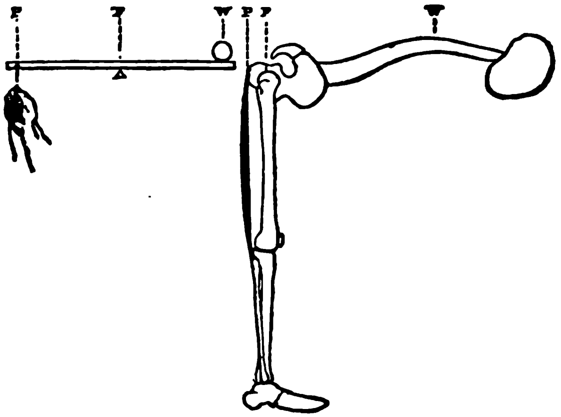


FIG. 288.

In a lever of the second kind, the arrangement is thus:—P.W.F.; and this leverage is employed in the act of raising the handles of a wheelbarrow, or in stretching an elastic band as in Fig. 289. In the human body the act of opening the mouth by depressing the lower jaw is an example of the same kind,—the tension of the muscles which close the jaw representing the weight (Fig. 289).

In a lever of the third kind the arrangement is—F.P.W., and the act of raising a pole, as in Fig. 290, is an example. In the human body there are numerous examples of the employment of this kind of leverage. The act of bending the fore-arm may be mentioned as an instance (Fig. 290). The act of biting is another example.

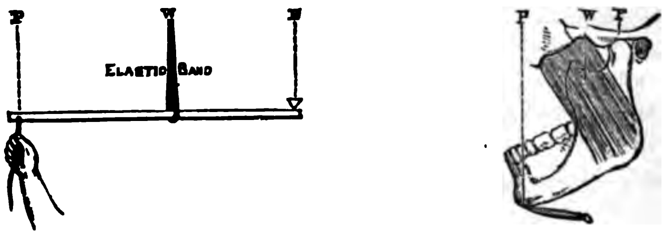


FIG. 289.

At the ankle we have examples of all three kinds of lever. 1st kind—Extending the foot. 3rd kind—Flexing the foot. In both these cases the foot represents the weight: the ankle joint the fulcrum, the power being the calf muscles in the first case, and the tibialis anticus in the second case. 2nd kind—When the body is raised on tip-toe. Here the ground is the fulcrum, the weight of the body acting at the ankle joint the weight, and the calf muscles the power.

In the human body, levers are most frequently used at a disadvantage as regards power, the latter being sacrificed for the sake of a greater range of motion. Thus in the diagrams of the first and third kinds it is evident that the power is so close to the fulcrum, that great force must be exercised in order to produce motion. It is also evident, however, from the same diagrams, that by the closeness of the power to the fulcrum a great range of movement can be obtained by means of a comparatively slight shortening of the muscular fibres.

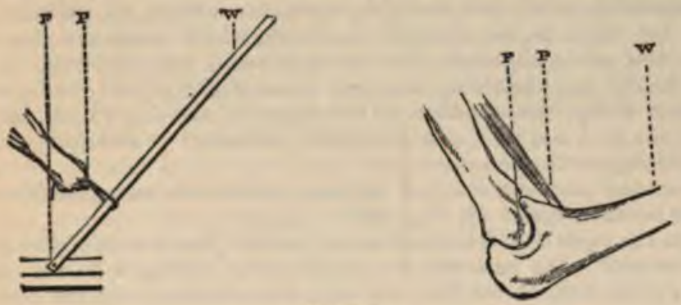


FIG. 290.

The greater number of the more important muscular actions of the human body—those, namely, which are arranged harmoniously so as to subserve some definite purpose or other in the animal economy—are described in various parts of this work, in the sections which treat of the physiology of the processes by which these muscular actions are resisted or carried out. There are, however, one or two very important and somewhat complicated muscular acts which may be best described in this place.

Walking.—In the act of walking, almost every voluntary muscle in the body is brought into play, either directly for purposes of progression, or indirectly for the proper balancing of the head and trunk. The muscles of the arms are least concerned; but even these are for the most part instinctively in action also to some extent.

Among the chief muscles engaged directly in the act of walking are those of the calf, which, by pulling up the heel, pull up also the astragalus, and with it, of course, the whole body, the weight of which is transmitted through the tibia to this bone (Fig. 291). When starting to walk, say with the left leg, this raising of the body is not left entirely to the muscles of the left calf, but the trunk is thrown forward in such a way that it would fall prostrate were it not that the right foot is brought forward and planted on the ground to support it. Thus the muscles of the left calf are assisted in their action by those muscles on the front of the trunk and legs which, by their contraction, pull the body forward; and, of course, if the trunk form a slanting line, with the inclination forward, it is plain that when the heel is raised by the calf-muscles, the whole body will be raised, and pushed obliquely forward and upward. The successive acts in taking the first step in walking are represented in Fig. 291, 1, 2, 3.

Now it is evident that by the time the body has assumed the position No. 3, it is time that the right leg should be brought forward to support it and prevent it from falling prostrate. This advance of the other leg (in this case the *right*) is effected partly by its mechanically swinging forward, pendulum-wise, and partly by muscular action; the muscles used being,—1*st*, those on the front of the *thigh*, which bend the thigh forward on the pelvis, especially the rectus femoris, with the psoas and the iliacus; 2*ndly*, the hamstring muscles, which slightly bend the *leg* on the thigh; and 3*rdly*, the muscles on the front of the *leg*, which raise the front of the foot and toes, and so prevent the latter in swinging forward from hitching in the ground.

The second part of the act of walking, which has been just described, is shown in the diagram (4, Fig. 291).

When the *right* foot has reached the ground the action of the *left* leg has not ceased. The calf-muscles of the latter continue to act, and by pulling up the heel, throw the body still more forward over the *right* leg, now bearing nearly the whole weight, until it is time that in *its* turn the *left* leg should swing forward, and the left foot be planted on the ground to prevent the body from falling prostrate. As at first, while the calf-muscles of one leg and foot are preparing, so to speak, to *push* the body forward and upward from behind by raising the heel, the muscles on the *front* of the trunk and of the same leg (and of the other leg, except when it is swinging forward) are helping the act by *pulling* the legs and trunk, so as to make them incline forward, the rotation in the inclining forward being effected mainly at the ankle joint. Two main kinds of leverage are, therefore, employed in the act of walking, and if this idea be firmly grasped, the detail will be understood with comparative ease. One kind of leverage employed in walking is essentially the same with that employed in pulling forward the pole, as in Fig. 290. And the other, less exactly, is that employed in raising the handles of a wheelbarrow. Now, supposing the lower end of the pole to be placed in the barrow, we should have a very rough and inelegant, but not altogether bad representation of the two main levers employed in the act of walking. The body is *pulled* forward by the muscles in front, much in the same way that the pole might be by the force applied at P (Fig. 290), while the raising of the heel and *pushing* forward of the trunk by the calf-muscles is roughly represented on raising the handles of the barrow. The manner in which these actions are performed alternately by each leg, so that one after the other is swung forward to support the trunk, which is at the same time *pushed* and *pulled* forward by the muscles of the other, may be gathered from the previous description.

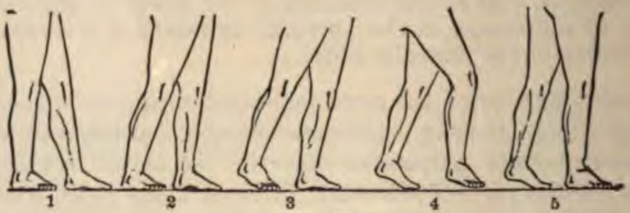


FIG. 291.

There is one more thing to be noticed especially in the act of walking. Inasmuch as the body is being constantly supported and balanced on each leg alternately, and therefore on only one at the same moment, it is evident that there must be some provision made for throwing the centre of gravity over the line of support formed by the bones of each leg, as, in its turn, it supports the weight of the body. This may be done in various ways, and the manner in which it is effected is one element in the differences which exist in the walking of different people. Thus it may be done by an instinctive slight rotation of the pelvis on the head of each femur in turn, in such a manner that the centre of gravity of the body shall fall over the foot of this side. Thus when the body is pushed onward and upward by the raising, say, of the *right* heel, as in Fig. 291, 3, the pelvis is instinctively by various muscles, made to rotate on the head of the left femur at the acetabulum, to the left side, so that the weight may fall over the line of support formed by the left leg at the time that the *right* leg is swinging forward, and leaving all the work of support to fall on its fellow. Such a "rocking" movement of the trunk and pelvis, however, is accompanied by a movement of the whole trunk and leg over the foot which is being planted on the ground (Fig. 292); the action being accompanied with a compensatory outward movement at the hip, more easily appreciated by looking at the figure (in which this movement is shown exaggerated) than described.

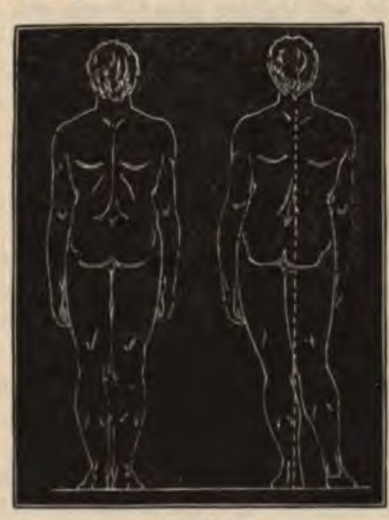


FIG. 292.

Thus the body in walking is continually rising and swaying alternately from one side to the other, as its centre of gravity has to be brought alternately over one or other leg; and the curvatures of the spine are altered in correspondence with the varying position of the weight which it has to support. The extent to which the body is raised or swayed differs much in different people.

In walking, one foot or the other is always on the ground. The act of *leaping* or *jumping*, consists in so sudden a raising of the heels by the sharp and strong contraction of the calf-muscles, that the body is jerked off the ground. At the same time the effect is much increased by first bending the thighs on the pelvis, and the legs on the thighs, and then suddenly straightening out the angles thus formed. The share which this action has in producing the effect may be easily known by attempting to leap in the upright posture, with the legs quite straight.

Running is performed by a series of rapid low jumps with each leg alternately; so that, during each complete muscular act concerned, there is a moment when both feet are off the ground.

In all these cases, however, the description of the manner in which any given effect is produced, can give but a very imperfect idea of the infinite number of combined and harmoniously arranged muscular contractions which are necessary for even the simplest acts of locomotion.

Actions of the Involuntary Muscles.—The involuntary muscles are for the most part not attached to bones arranged to act as levers, but enter into the formation of such hollow parts as require a diminution of their calibre by muscular action, under particular circumstances. Examples of this action are to be found in the intestines, urinary bladder, heart and blood-vessels, gall-bladder, gland-ducts, etc.

The difference in the manner of contraction of the striated and non-striated fibres has been already referred to (p. 36, Vol. II.); and the peculiar vermicular or peristaltic action of the latter fibres has been described at p. 36, Vol. II.

SOURCE OF MUSCULAR ACTION.

It was formerly supposed that each act of contraction on the part of a muscle was accompanied by a correlative waste or destruction of its own substance; and that the quantity of the nitrogenous excreta, especially of urea, presumably the expression of this waste, was in exact proportion to the amount of muscular work performed. It has been found, however, both that the theory itself is erroneous, and that the supposed facts on which it was founded do not exist.

It is true that in the action of muscles, as of all other parts, there is a certain destruction of tissue, or, in other words, a certain "wear and tear," which may be represented by a slight increase in the quantity of urea excreted: but it is not the *correlative* expression or *only* source of the power manifested. The increase in the amount of urea which is excreted after muscular exertion is by no means so great as was formerly supposed; indeed, it is very slight. And as there is no reason to believ ethat the waste of muscle-substance can be expressed, with unimportant exceptions, in any other way than by an increased excretion of urea, it is evident that we must look elsewhere than in destruction of muscle, for the source of muscular action. For, it need scarcely be said, all force manifested in the living body must be the correlative expression of force previously latent in the food eaten or the tissue formed; and evidences of force expended in the body must be found in the *excreta*. If, therefore, the *nitrogenous* excreta, represented chiefly by urea, are not in sufficient quantity to account for the work done, we must look to the *non-nitrogenous* excreta as carbonic acid and water, which, presumably, cannot be the expression of wasted muscle-substance.

The quantity of these non-nitrogenous excreta is undoubtedly increased by active muscular efforts, and to a considerable extent; and whatever may be the source of the water, the carbonic acid, at least, is the result of chemical action in the system, and especially of the combustion of non-nitrogenous food, although, doubtless, of nitrogenous food also. We are, therefore, driven to the conclusion,—that the substance of muscles is not wasted in proportion to the work they perform; and that the non-nitrogenous as well as the nitrogenous foods may, in their combustion, afford the requisite conditions for muscular action. The urgent necessity for *nitrogenous* food, especially after exercise, is probably due more to the need of *nutrition* by the exhausted muscles and other tissues for which, of course, nitrogen is essential, than to such food being superior to *non-nitrogenous* substances as a source of muscular power.

The electrical condition of Nerves is so closely connected with the phenomena of muscular contraction, that it will be convenient to consider it in the present chapter.

Electrical currents in Nerves.—If a piece of nerve be removed from the body and subjected to examination in a way similar to that adopted in the case of muscle which has been described (p. 22, Vol. II.), electrical currents are found to exist which correspond exactly to the natural muscle currents, and which are called *natural nerve currents* or *currents of rest,* according as one or other theory of their existence be adopted, as in the case with muscle. One point (corresponding to the equator) on the surface being positive to all other points nearer to the cut ends, and the greatest deflection of the needle of the galvanometer taking place when one electrode is applied to the equator and the other to the centre of either cut end. As in the case of muscle, these nerve-currents undergo a *negative variation* when the nerve is stimulated, the variation being momentary and in the opposite direction to the natural currents; and are similarly known as the *currents of action*. The currents of action are propagated in both directions from the point of the application of the stimulus, and are of momentary duration.

Rheoscopic Frog.—The negative variation of the nerve current may be demonstrated by means of the following experiment.—The new current produced by stimulating the nerve of one nerve-muscle preparation may be used to stimulate the nerve of a second nerve-muscle preparation. The fore-leg of a frog with the nerve going to the gastrocnemius cut long is placed upon a glass plate, and arranged in such a way that its nerve touches in two places the sciatic nerve, exposed but preserved *in* *situ* in the thigh of the opposite leg. The electrodes from an induction coil are placed behind the sciatic nerve of the second preparation, high up. On stimulating the nerve with a single induction shock, the muscles not only of the same leg are found to undergo a twitch, but also those of the first preparation, although this is not near the electrodes, and so the stimulation cannot be due to an escape of the current into the first nerve. This experiment is known under the name of the *rheoscopic frog.*

Nerve-stimuli.—Nerve-fibres require to be stimulated before they can manifest any of their properties, since they have no power of themselves of generating force or of originating impulses. The stimuli which are capable of exciting nerves to action, are, as in the case of muscle, very diverse. They are of very similar nature in each case. The mechanical, chemical, thermal, and electric stimuli which may be used in the one case are also, with certain differences in the methods employed, efficacious in the other. The chemical stimuli are chiefly these: withdrawal of water, as by drying, strong solutions of neutral salts of potassium, sodium, etc., free inorganic acids, except phosphoric; some organic acids; ether, chloroform, and bile salts. The electrical stimuli employed are the induction and continuous currents concerning which the observations in reference to muscular contraction should be consulted, p. 26, *et seq.*, Vol. II. Weaker electrical stimuli will excite nerve than will excite muscle; the nerve stimulus appears to gain strength as it descends, and a weaker stimulus applied far from the muscle will have the same effect as a somewhat stronger one applied to the nerve near the muscle.

It will be only necessary here to add some account of the effect of a constant electrical current, such as that obtained from Daniell's battery, upon a nerve. This effect may be studied with the apparatus described before. A pair of electrodes are placed behind the nerve of the nerve-muscle preparation, with a Du Bois Reymond's key arranged for short circuiting the battery current, in such a way that when the key is opened the current is sent into the nerve, and when closed the current is cut off. It will be found that with a current of moderate strength there will be a contraction of the muscle both at the opening and at the closing of the key (called respectively *making* and *breaking* contractions), but that during the interval between these two events the muscle remains flaccid, provided the battery current continues of constant intensity. If the current be a very weak or a very strong one the effect is not quite the same; one or other of the contractions may be absent. Which of these contractions is absent depends upon another circumstance, viz., the direction of the current. The direction of the current may be *ascending* or *descending;* if ascending, the anode or positive pole is nearer the muscle than the kathode or negative pole, and the current to return to the battery has to pass up the nerve,—if descending, the position of the electrodes is reversed. It will be necessary before considering this question further to return to the want of apparent effect of the constant current during the interval between the make and break contraction: to all appearance, indeed, no effect is produced at all, but in reality a very important change is brought about in the nerve by the passage of the current. This may be shown in two ways, first of all by the galvanometer. If a piece of nerve be taken, and if at either end an arrangement be made to test the electrical condition of the nerve by means of a pair of non-polarizable electrodes connected with a galvanometer, while to the central portion a pair of electrodes connected with a Daniell's battery be applied, it will be found that the natural nerve-currents are profoundly altered on the passage of the constant current (which is called the polarizing current) in the neighborhood. If the polarizing current be in the same direction as the latter the natural current is increased, but if in the direction opposite to it, the natural current is diminished. This change, produced by the continual passage of the battery-current through a portion of the nerve is to be distinguished from the negative variation of the natural current to which allusion has been already made, and which is a momentary change occurring on the sudden application of the stimulus. The condition produced in a nerve by the passage of a constant current is known by the name of *electrotonus*.

The other way of showing the effect of the same polarizing current is by taking a nerve-muscle preparation and applying to the nerves a pair of electrodes from an induction coil whilst at a point further removed from the muscle, electrodes from a Daniell's battery are arranged with a key for short circuiting and an apparatus (reverser) by which the battery current may be reversed in direction. If the exact point be ascertained to which the secondary coil should be moved from the primary coil in order that a minimum contraction be obtained by the induction shock, and the secondary coil be removed slightly further from the primary, the induction current cannot now produce a contraction; but if the polarizing current be sent in a descending direction, that is to say, with the kathode nearest the other electrodes, the induction current, which was before insufficient, will prove sufficient to cause a contraction; whereby indicating that with a descending current the irritability of the nerve is increased. By means of a somewhat similar experiment it may be shown that an ascending current will diminish the irritability of a nerve. Similarly, if instead of applying the induction electrodes below the other electrodes they are applied between them, like effects are demonstrated, indicating that in the neighborhood of the kathode the irritability of the nerve is increased by a constant current, and in the neighborhood of the anode diminished. This increase in irritability is called *katelectrotonus*, and similarly the decrease is called *anelectrotonus*. As there is between the electrodes both an increase and a decrease of irritability on the passage of a polarizing current it must be evident that the increase must shade off into the decrease, and that there must be a neutral point where there is neither increase nor decrease of irritability. The position of this neutral point is found to vary with the intensity of the polarizing current; when the current is weak the point is nearer the anode, when strong nearer the kathode (Fig. 293). When a constant current passes into a nerve, therefore, if a making contraction result, it may be assumed that it is due to the increased irritability produced in the neighborhood of the kathode, but the breaking contraction must be produced by a rise in irritability from a lowered state to the normal in the neighborhood of the anode. The contractions produced in the muscle of a nerve-muscle preparation by a constant current have been arranged in a table which is known as Pflüger's Law of Contractions. It is really only a statement as to when a contraction may be expected:—

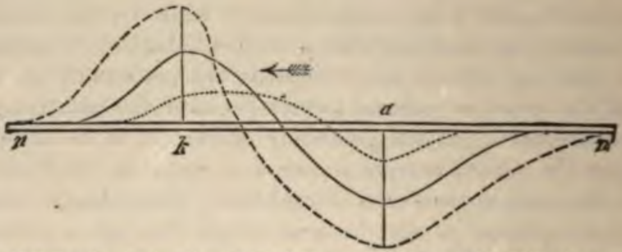


FIG. 293.—Diagram illustrating the effects of various intensities of the polarizing currents. *n*, *n'* nerve; *a*, anode; *k*, kathode; the curves above indicate increase, and those below decrease of irritability, and when the current is small the increase and decrease are both small, with the neutral point near *a*, and so on as the current is increased in strength.

DESCENDING CURRENT.			ASCENDING CURRENT.	
	Make.	Break.	Make.	Break.
Weak . . .	Yes.	No.	Yes.	No.
Moderate . .	Yes.	Yes.	Yes.	Yes.
Strong . .	Yes.	No.	No.	Yes.

The difficulty in this table is chiefly in the effect of a weak current, but the following statement will explain it. The increase of irritability at the kathode is more potent to produce a contraction than the rise of irritability from a lower to a normal condition at the anode. With weak currents the only effect is a contraction at the make of both ascending and descending currents, the descending current being more potent than the ascending (and with still weaker currents is the only one which produces any effect), since the kathode is near the muscle, whereas in the case of the ascending current the stimulus has to pass through a district of diminished irritability, which may either act as an entire block, or may diminish slightly the contraction which follows. As the polarizing current becomes stronger, recovery from anelectrotonus is able to produce a contraction as well as katelectrotonus, and a contraction occurs both at the make and the break of the current. The absence of contraction with a very strong current at the break of the ascending current may be explained by supposing that the region of fall in irritability at the kathode blocks the stimulus of the rise in irritability at the anode.

Thus we have seen that two circumstances influence the effect of the constant current upon a nerve, viz., the strength and direction of the current. It is also necessary that the stimulus should be applied suddenly and not gradually, and that the irritability of the nerve be normal, and not increased or diminished. Sometimes (when the nerve is specially irritable?) instead of a simple contraction a tetanus occurs at the make or break of the constant current. This is especially liable to occur at the break of a strong ascending current which has been passing for some time into the preparation; this is called *Ritter's tetanus*, and may be increased by passing a current in an opposite direction or stopped by passing a current in the same direction.

CHAPTER XVI.

THE VOICE AND SPEECH.

In nearly all air-breathing vertebrate animals there are arrangements for the production of sound, or *voice*, in some parts of the respiratory apparatus. In many animals, the sound admits of being variously modified and altered during and after its production; and, in man, one such modification occurring in obedience to dictates of the cerebrum, is *speech*.

MODE OF PRODUCTION OF THE HUMAN VOICE.

It has been proved by observations on living subjects, by means of the laryngoscope, as well as by experiments on the larynx taken from the dead body, that the sound of the human voice is the result of the inferior laryngeal ligaments, or true vocal cords (A, *cv*, Fig. 298) which bound the *glottis*, being thrown into vibration by currents of expired air impelled over their edges. Thus, if a free opening exists in the trachea, the sound of the voice ceases, but returns if the opening is closed. An opening into the air-passages above the glottis, on the contrary, does not prevent the voice being formed. Injury of the laryngeal nerves supplying the muscles which move the vocal cords puts an end to the formation of vocal sounds; and when these nerves are divided on both sides, the loss of voice is complete. Moreover, by forcing a current of air through the larynx in the dead subject, clear vocal sounds are produced, though the epiglottis, the upper ligaments of the larynx or false vocal cords, the ventricles between them and the inferior ligaments or true vocal cords, and the upper part of the arytenoid cartilages, be all removed; provided the true vocal cords remain entire, with their points of attachment, and be kept tense and so approximated that the fissure of the glottis may be narrow.

The vocal ligaments or cords, therefore, may be regarded as the proper organs of the mere voice: the modifications of the voice being effected by other parts—tongue, teeth, lips, etc., as well as by them. The structure of the vocal cords is adapted to enable them to vibrate like tense membranes, for they are essentially composed of elastic tissue; and they are so attached to the cartilaginous parts of the larynx that their position and tension can be variously altered by the contraction of the muscles which act on these parts.

The Larynx.—The *larynx,* or organ of voice, consists essentially of the two vocal cords, which are so attached to certain cartilages, and so under the control of certain muscles, that they can be made the means not only of closing the aperture of the larynx (rima glottidis), of which they are the lateral boundaries, against the entrance and exit of air to or from the lungs, but also can be stretched or relaxed, shortened or lengthened, in accordance with the conditions that may be necessary for the air in passing over them, to set them vibrating and produce various sounds.

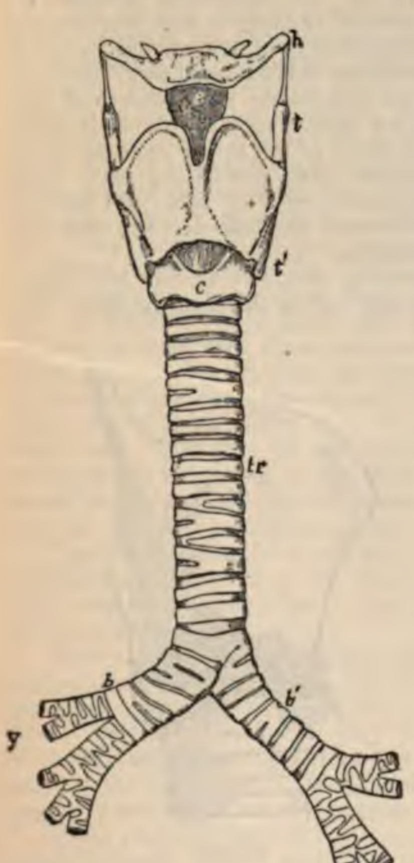


FIG. 294.

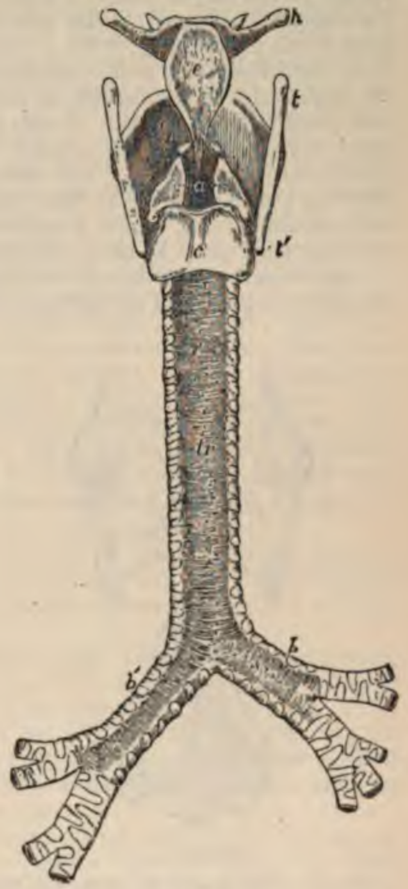


FIG. 295.

FIG. 294.—Outline showing the general form of the larynx, trachea, and bronchi, as seen from before. *h*, the great cornu of the hyoid bone; *e*, epiglottis; *t*, superior, and *t'*, inferior cornu of the thyroid cartilage; *c*, middle of the cricoid cartilage; *tr*, the trachea, showing sixteen cartilaginous rings; *b*, the right, and *b'*, the left bronchus. × ½. (Allen Thomson.)

FIG. 295.—Outline showing the general form of the larynx, trachea, and bronchi, as seen from behind. *h*, great cornu of the hyoid bone; *t*, superior, and *t'*, the inferior cornu of the thyroid cartilage; *e*, the epiglottis; *a*, points to the back of both the arytenoid cartilages, which are surmounted by the cornicula; *c*, the middle ridge on the back of the cricoid cartilage; *tr*, the posterior membranous part of the trachea; *b*, *b'*, right and left bronchi. × ½. (Allen Thomson.)

Their action in respiration has been already referred to (p. 189, Vol. I.). In the present chapter the sound produced by the vibration of the vocal cords is the only part of their function with which we have to deal.

Anatomy of the Larynx.—The principal parts entering into the formation of the larynx (Figs. 294 and 295) are—(*t*) the thyroid cartilage; (*c*) the cricoid cartilage; (*a*) the two arytenoid cartilages; and the two true vocal cords (A, *cv*, Fig. 298). The epiglottis (Fig. 298 *e*), has but little to do with the voice, and is chiefly useful in falling down as a "lid" over the upper part of the larynx, to help in preventing the entrance of food and drink in deglutition. It also guides mucus or other fluids in small amount from the mouth around the sides of the upper opening of the glottis into the pharynx and œsophagus: thus preventing them from entering the larynx. The false vocal cords (*cvs*, Fig. 298), and the ventricle of the larynx, which is a space between the false and the true cord of either side, need be here only referred to.

Cartilages.—The thyroid cartilage (Fig. 296, 1 to 4) does not form a complete ring around the larynx, but only covers the front portion. The cricoid cartilage (Fig. 296, 5, 6), on the other hand, is a complete ring; the back part of the ring being much broader than the front. On the top of this broad portion of the cricoid are the arytenoid cartilages (Fig. 298 *a*) the connection between the cricoid below and arytenoid cartilages above being a joint with synovial membrane and ligaments, the latter permitting tolerably free motion between them. But although the arytenoid cartilages can move on the cricoid, they of course accompany the latter in all their movements, just as the head may nod or turn on

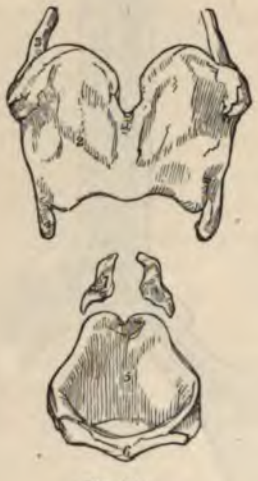


FIG. 296.

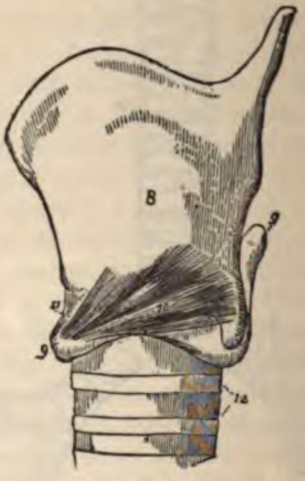


FIG. 297.

FIG. 296.—Cartilages of the larynx seen from before. 1 to 4, thyroid cartilage; 1, vertical ridge or pomum Adami; 2, right ala; 3, superior, and 4, inferior cornu of the right side; 5, 6, cricoid cartilage; 5, inside of the posterior part; 6, anterior narrow part of the ring; 7, arytenoid cartilages. × ¾.

FIG. 297.—Lateral view of exterior of the larynx. 8, thyroid cartilage; 9, cricoid cartilage; 10, crico-thyroid muscle; 11, crico-thyroid ligament; 12, first rings of trachea. (Willis.)

the top of the spinal column, but must accompany it in all its movements as a whole.

Ligaments.—The thyroid cartilage is also connected with the cricoid, not only by ligaments, but by two joints with synovial membrane (t′, Figs. 294 and 295); the lower *cornua* of the thyroid clasping, or nipping, as it were, the cricoid between them, but not so tightly but that the thyroid can revolve, within a certain range, around an axis passing transversely through the two joints at which the cricoid is clasped. The vocal cords are attached (behind) to the front portion of the base of the arytenoid cartilages, and (in front) to the re-entering angle at the back part of the thyroid; it is evident, therefore, that all movements of either of these cartilages must produce an effect on them of some kind or other. Inasmuch, too, as the arytenoid cartilages rest on the top of the back portion of the cricoid cartilage (*a*, Fig. 298), and are connected with it by capsular and other ligaments, all movements of the cricoid cartilage must move the arytenoid cartilages, and also produce an effect on the vocal cords.

Intrinsic Muscles.—The so-called *intrinsic* muscles of the larynx, or those which, in their action, have a direct action on the vocal cords, are nine in number—four pairs, and a single muscle; namely, two *crico-thyroid* muscles, two *thyro-arytenoid*, two *posterior crico-arytenoid*, two *lateral crico-arytenoid*, and one *arytenoid* muscle. Their actions are as follows:—When the *crico-thyroid* muscles (10, Fig. 297) contract, they rotate the cricoid on the thyroid cartilage in such a manner that the upper and back part of the former, and of necessity the arytenoid cartilages on the top of it, are tipped backward, while the thyroid is inclined forward: and thus, of course, the vocal cords being attached in front to one, and behind to the other, are "put on the stretch."

The *thyro-arytenoid* muscles (7, Fig. 300) on the other hand, have an opposite action,—pulling the *thyroid* backward, and the *arytenoid* and upper and back part of the *cricoid* cartilages forward, and thus *relaxing* the vocal cords.

The *crico-arytenoidei posticus* muscles (Fig. 299, *b*) *dilate* the glottis, and separate the vocal cords, the one from the other, by an action on the arytenoid cartilage which will be plain on reference to B′ and C′, (Fig. 298). By their contraction they tend to *pull together* the outer angles of the arytenoid cartilages in such a fashion as to rotate the latter at their joint with the cricoid, and of course to throw asunder their anterior angles to which the vocal cords are attached.

These *posterior* crico-arytenoid muscles are opposed by the *crico-arytenoidei laterales*, which, pulling in the opposite direction from the other side of the axis of rotation, have of course exactly the opposite effect, and close the glottis (Fig. 300, 4 and 5).

The aperture of the glottis can be also contracted by the *arytenoid* muscle (*s*, Fig. 299, and 6, Fig. 300), which, in its contraction, pulls together the upper parts of the arytenoid cartilages between which it extends.

Nerve supply.—In the performance of the functions of the larynx the sensory filaments of the pneumogastric supply that acute sensibility by which the glottis is guarded against the ingress of foreign bodies, or of irrespirable gases. The contact of these stimulates the filaments of the superior laryngeal branch of the pneumogastric; and the impression conveyed to the medulla oblongata, whether it produce sensation or not, is reflected to the filaments of the recurrent or inferior laryngeal branch, and excites contraction of the muscles that close the glottis. Both these branches of pneumogastric co-operate also in the production and regulation of the voice; the inferior laryngeal determining the contraction of the muscles that vary the tension of the vocal cords, and the superior laryngeal conveying to the mind the sensation of the state of these muscles necessary for their continuous guidance. And both the branches co-operate in the actions of the larynx in the ordinary slight dilatation and contraction of the glottis in the acts of expiration and inspiration, and more evidently in those of coughing and other forcible respiratory movements.

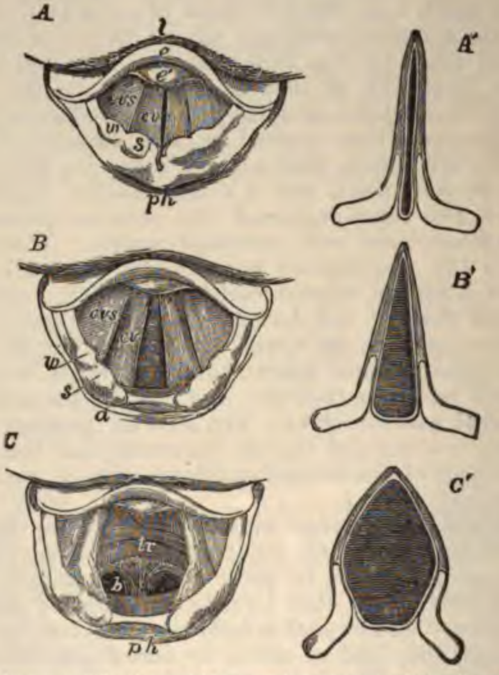


FIG. 298.—Three laryngoscopic views of the superior aperture of the larynx and surrounding parts. A, the glottis during the emission of a high note in singing; B, in easy and quiet inhalation of air; C, in the state of widest possible dilatation, as in inhaling a very deep breath. The diagrams A′, B′, and C′, have been added to Czermak's figures, to show in horizontal sections of the glottis the position of the vocal ligaments and arytenoid cartilages in the three several states represented in the other figures. In all the figures, so far as marked, the letters indicate the parts as follows, viz.: *l*, the base of the tongue; *e*, the upper free part of the epiglottis; *e′*, the tubercle or cushion of the epiglottis; *ph*, part of the anterior wall of the pharynx behind the larynx; in the margin of the aryteno-epiglottidean fold *w*, the swelling of the membrane caused by the cartilages of Wrisberg; *s*, that of the cartilages of Santorini; *a*, the tip or summit of the arytenoid cartilages; *c v*, the true vocal cords or lips of the rima glottidis; *c v s*, the superior or false vocal cords; between them the ventricle of the larynx; in C, *tr* is placed on the anterior wall of the receding trachea, and *b* indicates the commencement of the two bronchi beyond the bifurcation which may be brought into view in this state of extreme dilatation. (Czermak.) (From Quain's Anatomy.)

Movements of Vocal Cords.—The placing of the vocal cords in a position parallel one with the other, is effected by a combined action of the various little muscles which act on them—the thyro-arytenoidei having, without much reason, the credit of taking the largest share in the production of this effect. Fig. 298 is intended to show the various positions of the vocal cord under different circumstances. Thus, in ordinary tranquil breathing, the opening of the glottis is wide and triangular (B) becoming a little wider at each inspiration, and a little narrower at each expiration. On making a rapid and deep inspiration the opening of the glottis is widely dilated (as in C), and somewhat lozenge-shaped. At the moment of the emission of sound, it is narrowed, the margins of the arytenoid cartilages being brought into contact and the edges of the vocal cords approximated and made parallel, at the same time that their tension is much increased. The higher the note produced, the tenser do the cords become (Fig. 298, A); and the range of a voice depends, of course, in the main, on the extent to which the degree of tension of the vocal cords can be thus altered. In the production of a high note, the vocal cords are brought well within sight, so as to be plainly visible with the help of the laryngoscope. In the utterance of grave tones, on the other hand, the epiglottis is depressed and brought over them, and the arytenoid cartilages look as if they were trying to hide themselves under it (Fig. 301). The *epiglottis*, by being somewhat pressed down so as to cover the superior cavity of the larynx, serves to render the notes deeper in tone, and at the same time somewhat duller, just as covering the end of a short tube placed in front of caoutchouc tongues lowers the tone. In no other respect does the epiglottis appear to have any effect in modifying the vocal sounds.

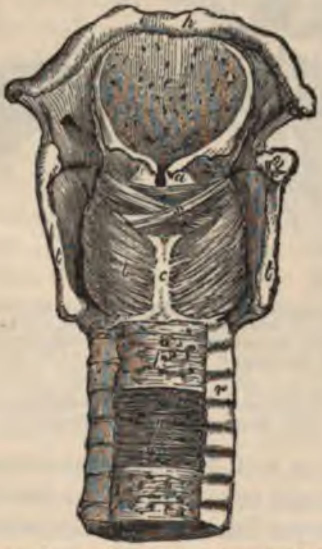


FIG. 299.—View of the larynx and part of the trachea from behind, with the muscles dissected; *h*, the body of the hyoid bone; *e*, epiglottis; *t*, the posterior borders of the thyroid cartilage; *c*, the median ridge of the cricoid; *a*, upper part of the arytenoid; *s*, placed on one of the oblique fasciculi of the arytenoid muscle; *b*, left posterior crico-arytenoid muscle; ends of the incomplete cartilaginous rings of the trachea; *l*, fibrous membrane crossing the back of the trachea; *n*, muscular fibres exposed in a part (from Quain's Anatomy).

The degree of approximation of the vocal cords also usually corresponds with the height of the note produced; but probably not always, for the width of the aperture has no essential influence on the height of the note, as long as the vocal cords have the same tension: only with a wide aperture, the tone is more difficult to produce, and is less perfect, the rushing of the air through the aperture being heard at the same time.

No true vocal sound is produced at the posterior part of the aperture of the glottis, that, viz., which is formed by the space between the arytenoid cartilages. For, as Müller's experiments showed, if the arytenoid cartilages be approximated in such a manner that their anterior processes touch each other, but yet leave an opening behind them as well as in front, no second vocal tone is produced by the passage of the air through the posterior opening, but merely a rustling or bubbling sound; and the height or pitch of the note produced is the same whether the posterior part of the glottis be open or not, provided the vocal cords maintain the same degree of tension.

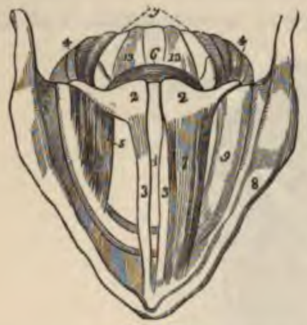


FIG. 300.

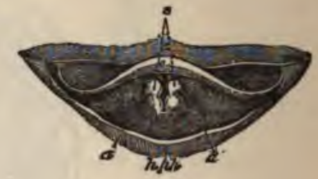


FIG. 301.

FIG. 300.—View of the anterior of larynx from above. 1, aperture of glottis; 2, arytenoid cartilages; 3, vocal cords; 4, posterior crico-arytenoid muscles; 5, lateral crico-arytenoid muscle of right side, that of left side removed; 6, arytenoid muscle; 7, thyro-arytenoid muscle of left side, that of right side removed; 8, thyroid cartilage; 9, cricoid cartilage; 13, posterior crico-arytenoid ligament. (Willis.)

FIG. 301.—View of the upper part of the larynx as seen by means of the laryngoscope during the utterance of a grave note. *c*, epiglottis; *s*, tubercles of the cartilages of Santorini; *a*, arytenoid cartilages; *z*, base of the tongue; *hph*, the posterior wall of the pharynx. (Czermak.)

APPLICATION OF THE VOICE IN SINGING AND SPEAKING.

Varieties of Vocal Sounds.—The notes of the voice thus produced may observe three different kinds of sequence. *The first* is the monotonous, in which the notes have nearly all the same pitch as in ordinary speaking; the variety of the sounds of speech being due to articulation in the mouth. In speaking, however, occasional syllables generally receive a higher intonation for the sake of accent. *The second mode* of sequence is the successive transition from high to low notes, and *vice versâ*, without intervals; such as is heard in the sounds, which, as expressions of passion, accompany crying in men, and in the howling and whining of dogs. *The third mode* of sequence of the vocal sounds is the musical, in which each sound has a determinate number of vibrations, and the numbers of the vibrations in the successive sounds have the same relative proportions that characterize the notes of the musical scale.

Compass of the Voice.—In different individuals this comprehends one, two, or three octaves. In singers—that is, in persons apt for singing—it extends to two or three octaves. But the male and female voices commence and end at different points of the musical scale. The lowest note of the female voice is about an octave higher than the lowest of the male voice; the highest note of the female voice about an octave higher than the highest of the male. The compass of the male and female voices taken together, or the entire scale of the human voice, includes about four octaves. The principal difference between the male and female voice is, therefore, in their *pitch;* but they are also distinguished by their *tone,*—the male voice is not so soft.

Pitch and Timbre.—The voice presents other varieties besides that of male and female; there are two kinds of male voice, technically called the bass and tenor, and two kinds of female voice, the contralto and soprano, all differing from each other in tone. The bass voice usually reaches lower than the tenor, and its strength lies in the low notes; while the tenor voice extends higher than the bass. The contralto voice has generally lower notes than the soprano, and is strongest in the lower notes of the female voice; while the soprano voice reaches higher in the scale. But the difference of compass, and of power in different parts of the scale, is not the essential distinction between the different voices; for bass singers can sometimes go very high, and the contralto frequently sings the high notes like soprano singers. The essential difference between the bass and tenor voices, and between the contralto and soprano, consists in their tone or "timbre," which distinguishes them even when they are singing the same note. The qualities of the baritone and mezzo-soprano voices are less marked; the baritone being intermediate, between the bass and tenor, the mezzo-soprano between the contralto and soprano. They have also a middle position as to pitch in the scale of the male and female voices.

The different pitch of the male and the female voices depends on the different length of the vocal cords in the two sexes; their relative length in men and women being as three to two. The difference of the two voices in tone or "timbre," is owing to the different nature and form of the resounding walls, which in the male larynx are much more extensive, and form a more acute angle anteriorly. The different qualities of the tenor and bass, and of the alto and soprano voices, probably depend on some peculiarities of the ligaments, and the membranous and cartilaginous parietes of the laryngeal cavity, which are not at present understood, but of which we may form some idea, by recollecting that musical instruments made of different materials, *e.g.*, metallic and gut-strings, may be tuned to the same note, but that each will give it with a peculiar tone or "timbre."

Varieties of Voices.—The larynx of boys resembles the female larynx; their vocal cords before puberty have not two-thirds the length which they acquire at that period; and the angle of their thyroid cartilage is as little prominent as in the female larynx. Boys' voices are alto and soprano, resembling in pitch those of women, but louder, and differing somewhat from them in tone. But, after the larynx has undergone the change produced during the period of development at puberty, the boy's voice becomes bass or tenor. While the change of form is taking place, the voice is said to "crack;" it becomes imperfect, frequently hoarse and crowing, and is unfitted for singing until the new tones are brought under command by practice. In eunuchs, who have been deprived of the testes before puberty, the voice does not undergo this change. The voice of most old people is deficient in tone, unsteady, and more restricted in extent: the first defect is owing to the ossification of the cartilages of the larynx and the altered condition of the vocal cord; the want of steadiness arises from the loss of nervous power and command over the muscles; the result of which is here, as in other parts, a tremulous motion. These two causes combined render the voices of old people void of tone, unsteady, bleating, and weak.

In any class of persons arranged, as in an orchestra, according to the character of voices, each would possess, with the general characteristics of a bass, or tenor, or any other kind of voice, some peculiar character by which his voice would be recognized from all the rest. The conditions that determine these distinctions are, however, quite unknown. They are probably inherent in the tissues of the larynx, and are as indiscernible as the minute differences that characterize men's features; one often observes, in like manner, hereditary and family peculiarities of voice, as well marked as those of the limbs or face.

Most persons, particularly men, have the power, if at all capable of singing, of modulating their voices through a double series of notes of different character: namely, the notes of the natural voice, or *chest-notes*, and the *falsetto notes*. The natural voice, which alone has been hitherto considered, is fuller, and excites a distinct sensation of much stronger vibration and resonance than the falsetto voice, which has more a flute-like character. The deeper notes of the male voice can be produced only with the natural voice, the highest with the falsetto only; the notes of middle pitch can be produced either with the natural or falsetto voice; the two registers of the voice are therefore not limited in such a manner as that one ends when the other begins, but they run in part side by side.

Method of the Production of Notes.—The natural or chest-notes are produced by the ordinary vibrations of the vocal cords. The mode of production of the falsetto notes is still obscure.

By Müller the falsetto notes were thought to be due to vibrations of only the inner borders of the vocal cords. In the opinion of Petrequin and Diday, they do not result from vibrations of the vocal cords at all, but from vibrations of the air passing through the aperture of the glottis, which they believe assumes, at such times, the contour of the *embouchure* of a flute. Others (considering some degree of similarity which exists between the falsetto notes and the peculiar tones called harmonic, which are produced when, by touching or stopping a harp-string at a particular point, only a portion of its length is allowed to vibrate) have supposed that, in the falsetto notes, portions of the vocal ligaments are thus isolated, and made to vibrate while the rest are held still. The question cannot yet be settled; but any one in the habit of singing may assure himself, both by the difficulty of passing smoothly from one set of notes to the other, and by the necessity of exercising himself in both registers, lest he should become very deficient in one, that there must be some great difference in the modes in which their respective notes are produced.

The strength of the voice depends partly on the degree to which the vocal cords can be made to vibrate; and partly on the fitness for resonance of the membranes and cartilages of the larynx, of the parietes of the thorax, lungs, and cavities of the mouth, nostrils, and communicating sinuses. It is diminished by anything which interferes with such capability of vibration. The intensity or loudness of a given note with maintenance of the same "pitch," cannot be rendered greater by merely increasing the force of the current of air through the glottis; for increase of the force of the current of air, *cæteris paribus*, raises the pitch both of the natural and the falsetto notes. Yet, since a singer possesses the power of increasing the loudness of a note from the faintest "piano" to "fortissimo" without its pitch being altered, there must be some means of compensating the tendency of the vocal cords to emit a higher note when the force of the current of air is increased. This means evidently consists in modifying the tension of the vocal cords. When a note is rendered louder and more intense, the vocal cords must be relaxed by remission of the muscular action, in proportion as the force of the current of the breath through the glottis is increased. When a note is rendered fainter, the reverse of this must occur.

The *arches of the palate and the uvula* become contracted during the formation of the higher notes; but their contraction is the same for a note of given height, whether it be falsetto or not; and in either case the arches of the palate may be touched with the finger, without the note being altered. Their action, therefore, in the production of the higher notes seems to be merely the result of involuntary associate nervous action, excited by the voluntarily increased exertion of the muscles of the larynx. If the palatine arches contribute at all to the production of the higher notes of the natural voice and the falsetto, it can only be by their increased tension strengthening the resonance.

The office of the *ventricles of the larynx* is evidently to afford a free space for the vibrations of the lips of the glottis; they may be compared with the cavity at the commencement of the mouth-piece of trumpets, which allows the free vibration of the lips.

SPEECH.

Besides the musical tones formed in the larynx, a great number of other sounds can be produced in the vocal tubes, between the glottis and the external apertures of the air-passages, the combination of which sounds by the agency of the cerebrum into different groups to designate objects, properties, actions, etc., constitutes *language*. The languages do not employ all the sounds which can be produced in this manner, the combination of some with others being often difficult. Those sounds which are easy of combination enter, for the most part, into the formation of the greater number of languages. Each language contains a certain number of such sounds, but in no one are all brought together. On the contrary, different languages are characterized by the prevalence in them of certain classes of these sounds, while others are less frequent or altogether absent.

Articulate Sounds.—The sounds produced in speech, or *articulate sounds*, are commonly divided into *vowels* and *consonants:* the distinction between which is, that the sounds for the former are generated by the larynx, while those for the latter are produced by interruption of the current of air in some part of the air-passages above the larynx. The term consonant has been given to these because several of them are not properly sounded, except *consonantly with* a vowel. Thus, if it be attempted to pronounce aloud the consonants *b*, *d*, and *g*, or their modifications, *p*, *t*, *k*, the intonation only follows them in their combination with a vowel. To recognize the essential properties of the articulate sounds, we must, according to Müller, first examine them as they are produced in whispering, and then investigate which of them can also be uttered in a modified character conjoined with vocal tone. By this procedure we find two series of sounds: in one the sounds are mute, and cannot be uttered with a vocal tone; the sounds of the other series can be formed independently of voice, but are also capable of being uttered in conjunction with it.

All the vowels can be expressed in a whisper without vocal tone, that is, mutely. These mute vowel-sounds differ, however, in some measure, as to their mode of production, from the consonants. All the mute consonants are formed in the vocal tube above the glottis, or in the cavity of the mouth or nose, by the mere rushing of the air between the surfaces differently modified in disposition. But the sound of the vowels, even when mute, has its source in the glottis, though its vocal cords are not thrown into the vibrations necessary for the production of voice; and the sound seems to be produced by the passage of the current of air between the relaxed vocal cords. The same vowel sound can be produced in the larynx when the mouth is closed, the nostrils being open, and the utterance of all vocal tone avoided. This sound, when the mouth is open, is so modified by varied forms of the oral cavity, as to assume the characters of the vowels *a, e, i, o, u,* in all their modifications.

The cavity of the mouth assumes the same form for the articulation of each of the mute vowels as for the corresponding vowel when vocalized; the only difference in the two cases lies in the kind of sound emitted by the larynx. Krantzenstein and Kempelen have pointed out that the conditions necessary for changing one and the same sound into the different vowels, are differences in the size of two parts—the oral canal and the oral opening; and the same is the case with regard to the mute vowels. By oral canal, Kempelen means here the space between the tongue and palate: for the pronunciation of certain vowels both the opening of the mouth and the space just mentioned are widened; for the pronunciation of other vowels both are contracted; and for others one is wide, the other contracted. Admitting five degrees of size, both of the opening of the mouth and of the space between the tongue and palate, Kempelen thus states the dimensions of these parts for the following vowel sounds:—

Vowel.	Sound.	Size of oral opening.	Size of oral canal.
a	as in "far"	5	3
a	" "name"	4	2
e	" "theme"	3	1
o	" "go"	2	4
oo	" "cool"	1	5

Another important distinction in articulate sounds is, that the utterance of some is only of momentary duration, taking place during a sudden change in the conformation of the mouth, and being incapable of prolongation by a continued expiration. To this class belong *b, p, d,* and the hard *g.* In the utterance of other consonants the sounds may be *continuous;* they may be prolonged, *ad libitum,* as long as a particular disposition of the mouth and a constant expiration are maintained. Among these consonants are *h, m, n, f, s, r, l.* Corresponding differences in respect to the time that may be occupied in their utterance exist in the vowel sounds, and principally constitute the differences of long and short syllables. Thus the *a* as in "far" and "fate," the *o* as in "go" and "fort," may be indefinitely prolonged; but the same vowels (or more properly different vowels expressed by the same letters), as in "can" and "fact," in "dog" and "rotten," cannot be prolonged.

All sounds of the first or explosive kind are insusceptible of combination with vocal tone ("intonation"), and are absolutely mute; nearly all the consonants of the second or continuous kind may be attended with "intonation."

Ventriloquism.—The peculiarity of speaking, to which the term *ventriloquism* is applied, appears to consist merely in the varied modification of the sounds produced in the larynx, in imitation of the modifications which voice ordinarily suffers from distance, etc. From the observations of Müller and Colombat, it seems that the essential mechanical parts of the process of ventriloquism consist in taking a full inspiration, then keeping the muscles of the chest and neck fixed, and speaking with the mouth almost closed, and the lips and lower jaw as motionless as possible, while air is very slowly expired through a very narrow glottis; care being taken also, that none of the expired air passes through the nose. But, as observed by Müller, much of the ventriloquist's skill in imitating the voices coming from particular directions, consists in deceiving other senses than hearing. We never distinguish very readily the direction in which sounds reach our ear; and, when our attention is directed to a particular point, our imagination is very apt to refer to that point whatever sounds we may hear.

Action of the Tongue in Speech.—The tongue, which is usually credited with the power of speech—*language* and speech being often employed as synonymous terms—plays only a subordinate, although very important part. This is well shown by cases in which nearly the whole organ has been removed on account of disease. Patients who recover from this operation talk imperfectly, and their voice is considerably modified; but the loss of speech is confined to those letters in the pronunciation of which the tongue is concerned.

Stammering depends on a want of harmony between the action of the muscles (chiefly abdominal) which expel air through the larynx, and that of the muscles which guard the orifice (rima glottidis) by which it escapes, and of those (of tongue, palate, etc.) which modulate the sound to the form of speech.

Over either of the groups of muscles, by itself, a stammerer may have as much power as other people. But he cannot harmoniously arrange their conjoint actions.

CHAPTER XVII.

NUTRITION; THE INCOME AND EXPENDITURE OF THE HUMAN BODY.

THE various physiological processes which occur in the human body have, with the exception of those in the nervous and generative systems, which will be considered in succeeding chapters, now been dealt with, and it will be as well to give in this chapter on Nutrition a summary of what has been considered more at length before.

The subject may be considered under the following heads. (1). The Evidence and Amount of Expenditure. (2). The Sources and Amount of Income. (3). The Sources and Objects of Expenditure.

1. **Evidence and Amount of Expenditure.**—The *evidence* of Expenditure by the living body is abundantly complete.

From the table (p. 212, Vol. I.) it will be seen how the various amounts of the excreta are calculated.

From theLungs there is exhaled every 24 hours,

Of Carbonic Acid, about	15,000 grains
" Water	5,000 "
Traces of organic matter.	
From the Skin—	
Water	11,500 grains
Solid and gaseous matter	250 "
From the Kidneys—	
Water	23,000 grains
Organic matter	680 "
Minerals or salines	420 "
From the Intestines—	
Water	2,000 grains
Various organic and mineral substances	800 "

In the account of Expenditure, must be remembered in addition the milk (during the period of suckling), and the products of secretion from the generative organs (ova, menstrual blood, semen); but, from their variable and uncertain amounts, these cannot be reckoned with the preceding.

Altogether, the Expenditure of the body represented by the sum of these various excretory products amounts every 24 hours to—

Solid and gaseous matter	17,150 grains (1,113 grms.)
Water (either fluid or combined with the solids and gaseous matter). .	49,500 " (2,695 ")

The matter thus lost by the body is matter the chemical attractions of which have been in great part satisfied; and which remains quite useless as food, until its elements have been again separated and re-arranged by members of the vegetable world (p. 2, Vol. I.). It is especially instructive to compare the chemical constitution of the products of expenditure, thus separated by the various excretory organs, with that of the sources of income to be immediately considered.

It is evident from these facts that if the human body is to maintain its size and composition, there must be added to it matter corresponding in amount with that which is lost. The income must equal the expenditure.

2. **Sources and Amount of Income.**—The Income of the body consists partly of *Food* and *Drink*, and partly of *Oxygen*.

Into the stomach there is received daily:—

Solid (chemically dry) food . .	8,000 grains (520 grms.)
Water (as water, or variously combined with solid food) . . .	35,000–40,000 " (2,444 ")

By the lungs there is absorbed daily:—

Oxygen	13,000 " 844 ")

The average total daily receipts, in the shape of food, drink and oxygen, correspond, therefore, with the average total daily expenditure, as shown by the following table:

Income.		*Expenditure.*	
Solid food . . .	8,000 grains	Lungs . . .	20,000 grains.
Water . . .	37,650 "	Skin . . .	11,750 "
Oxygen . . .	13,000 "	Kidneys . . .	24,100 "
		Intestines . .	2,800 "
	58,650 grains (about 3,808 grms., or 8⅓ lb.)	(Generative and mammary-gland products are supposed to be included.)	
			58,650 grains (About 3,808 grms.)

These quantities are approximate only. But they may be taken as fair averages for a healthy adult. The absolute identity of the two numbers (in *grains*) in the two tables is of course diagrammatic. No such exactitude in the account occurs in any living body, in the course of any given twenty-four hours. But any difference which exists between the two amounts of *income* and *expenditure* at any given period, corresponds merely with the slight variations, in the amount of *capital* (weight of body), to which the healthiest subject is liable.

The chemical composition of the food (p. 213, Vol. I.) may be profitably compared with that of the excreta, as before mentioned. The greater part of our food is composed of matter, which contains much potential energy; and in the chemical changes (combustion and other processes), to which it is subject in the body, active energy is manifested.

3. **The Sources and Objects of Expenditure.**—The sources of necessary waste and expenditure in the living body are various and extensive. They may be comprehended under the following heads:—(1) *Common wear and tear;* such as that to which all structures, living and not living, are subjected by exposure and work; but which must be especially large in the soft and easily decaying structures of an animal body.

(2) *Manifestations of Force in the form either of Heat or Motion.* In the former case (Heat), the combustion must be sufficient to maintain a temperature of about 100° F. (37·8° C.) throughout the whole substance of the body, in all varieties of external temperature, notwithstanding the large amount continually lost in the ways previously enumerated (p. 313, Vol. I.). In the case of Motion, there is the expenditure involved in (*a*) Ordinary muscular movements, as in Prehension, Mastication, Locomotion, and numberless other ways: (*b*) Various involuntary movements, as in Respiration, Circulation, Digestion, etc.

(3) *Manifestation of Nerve-force;* as in the general regulation of all physiological processes, *e.g.*, Respiration, Circulation, Digestion; and in Volition and all other manifestations of cerebral activity.

(4) *The energy expended in all physiological processes, e.g.*, Nutrition, Secretion, Growth, and the like.

The Total expenditure or manifestation of energy by an animal body can be measured, with fair accuracy; the terms used being such as are employed in connection with other than vital operations. All statements however, must be considered for the present approximate only, and especially is this the case with respect to the comparative share of expenditure to be assigned to the various objects just enumerated.

The amount of energy daily manifested by the adult human body in (*a*) the maintenance of its temperature; (*b*) in internal mechanical work, as in the movements of the respiratory muscles, the heart, etc.; and (*c*) in external mechanical work, as in locomotion and all other voluntary movements, has been reckoned at about 3,400 foot-tons (p. 124, Vol. I.). Of this amount only one-tenth is directly expended in internal and external mechanical work; the remainder being employed in the maintenance of the body's heat. The latter amount represents the heat which would be required to raise 48·4 lb. of water from the freezing to the boiling point; or if converted into mechanical power, it would suffice to raise the body of a man weighing about 150 lb. through a vertical height of 8½ miles.

To the foregoing amounts of expenditure must be added the quite unknown quantity expended in the various manifestations of nerve-force, and in the work of nutrition and growth (using these terms in their widest sense). By comparing the amount of energy which should be produced in the body from so much food of a given kind, with that which is actually manifested (as shown by the various products of combustion, in the excretions) attempts have been made, indeed, to estimate, by a process of exclusion, these unknown quantities: but all such calculations must be at present considered only very doubtfully approximate.

Sources of Error.—Among the sources of error in any such calculations must be reckoned, as a chief one, the, at present, entirely unknown extent to which forces external to the body (mainly heat) can be utilized by the tissues. We are too apt to think that the heat and light of the sun are directly correlated, as far as living beings are concerned, with the chemico-vital transformations involved in the nutrition and growth of the members of the vegetable world only. But animals, although comparatively independent of external heat and other forces, probably utilize them, to the degree occasion offers. And although the *correlative* manifestation of energy in the body, due to external heat and light, may still be measured in so far as it may take the form of mechanical work; yet, in so far as it takes the form of expenditure in nutrition or nerve-force, it is evidently impossible to include it by any method of estimation yet discovered; and all accounts of it must be matters of the purest theory. These considerations may help to explain the apparent discrepancy between the amount of energy which is capable of being produced by the usual daily amount of food, with that which is actually manifested daily by the body; the former leaving but a small margin for anything beyond the maintenance of heat, and mechanical work.

In the foregoing sketch we have supposed that the excreta are exactly replaced by the ingesta.

NITROGENOUS EQUILIBRIUM AND FORMATION OF FAT.

If an animal, which has undergone a starving period, be fed upon a diet of lean meat, it is found that instead of the greater part of the nitrogen being stored up, as one would expect, the chief part of it appears in the urine as urea, and on continuing with the diet the excreted nitrogen approximates more and more closely to the ingested nitrogen until at last the amounts are equal in both cases. This is called *nitrogenous equili-*

brium. There may, however, be at the same time an increase of weight which is due to the putting on of fat. If this is the case it must be apparent that the protoplasm of the tissues is able to form fat out of proteid material and to split it up into urea and fat. If fat be given in small quantities with the meat, for a time the carbon of the egesta and ingesta are equal, but if the fat be increased beyond a certain point the body weight increases from a deposition of fat; not, however, by a mere mechanical deposition or filtration from the blood, but by an actual act of secretion by the protoplasm whereby the fat globules are stored up within itself. In a similar manner as regards carbo-hydrates, if they are in small quantity, the whole of the carbon appears in the excreta, but beyond a certain amount a considerable portion of it is retained in fat, having been by the protoplasm stored up within itself in that material. The amount of proteid material required to produce nitrogenous equilibrium is considerable, but it may be materially diminished by the addition of carbo-hydrate or fatty food or of gelatine to the exclusively meat diet.

It is of much interest to consider how the protoplasm acts in converting food into energy and decomposition products, since the substance itself does not undergo much change in the process except a slight amount of wear and tear. We may assume that it is the property of protoplasm to separate from the blood the materials which may be required to produce secretions, in the case of the protoplasm of secreting glands, or to evolve heat and energy, as in the case of the protoplasm of muscle. The substances are very possibly different for each process, and the decomposition products, too, may be different in quality or quantity. Proteid materials appear to be specially needed, as is shown by the invariable presence of urea in the urine even during starvation; and as in the latter case, there has been no food from which these materials could have been derived, the urea is considered to be derived from the disintegration of the nitrogenous tissues themselves. The removal of all fat from the body in a starvation period, as the first apparent change, would lead to the supposition that fat is also a specially necessary pabulum for the production of protoplasmic energy; and the fact that, as mentioned above, with a diet of lean meat an enormous amount appears to be required, suggests that in that case protoplasm obtains the fat it needs from the proteid food, which process must be evidently a source of much waste of nitrogen. The idea that proteid food has two destinations in the economy, viz., to form organ or tissue proteid which builds up organs and tissues, and circulating proteid, from which the organs and tissues derive the materials of their secretions or for producing their energy, is a convenient one, as it is unlikely that protoplasm would go to the expense of construction simply for the sake of immediate destruction.

CHAPTER XVIII.

THE NERVOUS SYSTEM.

Chief Divisions of the Nervous System.—The Nervous System consists of two portions or systems, the (I.) *Cerebro-spinal*, and the (II.) *Sympathetic*.

(I.) The *Cerebro-spinal* system includes the Brain and Spinal cord, with the nerves proceeding from them. Its fibres are chiefly, but not exclusively, distributed to the skin and other organs of the senses, and to the voluntary muscles.

(II.) The *Sympathetic* Nervous system consists of:—(1) A double chain of ganglia and fibres, which extends from the cranium to the pelvis, along each side of the vertebral column, and from which branches are distributed both to the cerebro-spinal system and to other parts of the sympathetic system. With these may be included the small ganglia in connection with those branches of the fifth cerebral nerve which are distributed in the neighborhood of the organs of special sense: namely, the ***ophthalmic, otic,*** *spheno-palatine*, and *submaxillary* ganglia. (2) Various ganglia and plexuses of nerve-fibres which give off branches to the thoracic and abdominal viscera, the chief of such plexuses being the *Cardiac*, *Solar*, and *Hypogastric*; but in intimate connection with these are many secondary plexuses, as the *aortic*, *spermatic*, and *renal*. To these plexuses, fibres pass from the prevertebral chain of ganglia, as well as from cerebro-spinal nerves. (3) Various ganglia and plexuses in the substance of many of the viscera, as in the *stomach*, *intestines*, and *urinary bladder*. These, which are, for the most part, microscopic, also freely communicate with other parts of the sympathetic system, as well as, to some extent, with the cerebro-spinal. (4) By many, the ganglia on the *posterior roots of the spinal nerves*, on the *glosso-pharyngeal* and *vagus*, and on the ***sensory root*** *of the fifth cerebral nerve* (Gasserian ganglion), are also included as sympathetic-nerve structures.

Elementary Structure.—The organs both of the Cerebro-spinal and Sympathetic nervous systems are composed of two structural elements—*cells* and *fibres*. The cells are collected in masses, and are always mingled more or less with fibres; such a collection of cellular and fibrous nervous-matter being termed a nerve-centre. The fibres, besides entering into the composition of nerve-centres, form by themselves the ***nerves***, which connect the various centres, and are distributed in the several parts of the body.

NERVE FIBRES.

Structure.—Each nerve-trunk is composed of a variable number of different-sized bundles (*funiculi*) of nerve-fibres which have a special sheath (*perineurium* or *neurilemma*). The funiculi are enclosed in a firm fibrous sheath (*epineurium*); this sheath also sends in processes of connective tissue which connect the bundles together. In the funiculi between the fibres is a delicate supporting tissue (the *endoneurium*).

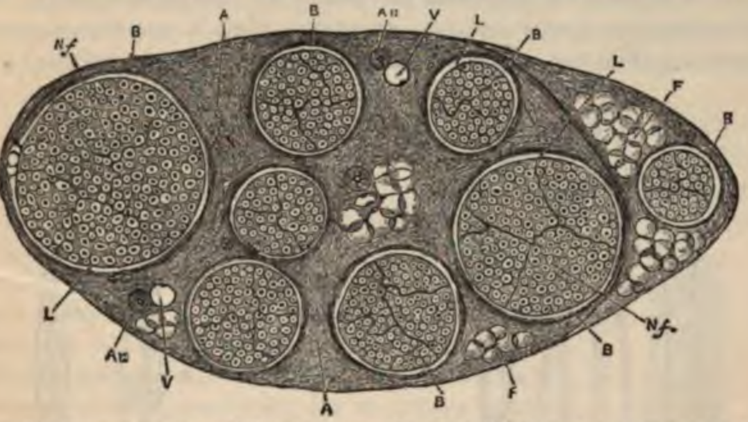


FIG. 302.—Transverse section of the sciatic nerve of a cat × 100.—It consists of bundles (*Funiculi*) of nerve-fibres ensheathed in a fibrous supporting capsule, *epineurium*, A; each bundle has a special sheath (not sufficiently worked out from the *epineurium* in the figure) or *perineurium* B; the nerve-fibres N*f* are separated from one another by *endoneurium*; L, lymph spaces; Ar, artery; V, vein; F, fat. (V. D. Harris.)

There are numerous lymph-spaces both beneath the connective tissue investing individual nerve-fibres, and also beneath that which surrounds the funiculi.

Varieties.—In most nerves, two kinds of fibres are mingled; those of one kind being most numerous in, and characteristic of, nerves of the Cerebro-spinal system; those of the other, most numerous in nerves of the Sympathetic system. These are called (A) medullated or white fibres, and (B) non-medullated or grey fibres.

(A) **Medullated Fibres.**—Each medullated nerve-fibre is made up of the following parts:—(1.) Primitive nerve sheath, or nucleated sheath of Schwann. (2) Medullary sheath, or white substance of Schwann. (3) Axis-cylinder, primitive band, axis band, or axial fibre.

Although these parts can be made out in nerves examined some time after death, in a recent specimen the contents of the sheath appear to be homogeneous. But by degrees they undergo changes which show them to be composed of two different materials. The internal or central part, occupying the axis of the tube (*axis-cylinder*), becomes greyish, while the outer, or cortical portion (*white substance of Schwann*), becomes opaque and dimly granular or grumous, as if from a kind of coagulation. At the same time, the fine outline of the previously transparent cylindrical tube is exchanged for a dark double contour (Fig. 303, B), the outer line being formed by the sheath of the fibre, the inner by the margin of curdled or coagulated medullary substance. The granular material shortly collects into little masses, which distend portions of the tubular membrane; while the intermediate spaces collapse, giving the fibres a varicose, or beaded appearance (Fig. 303, C and D), instead of the previous cylindrical form.

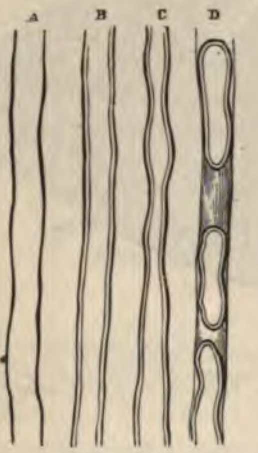


FIG. 303.

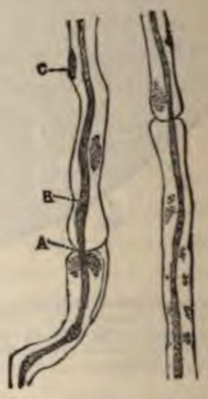


FIG. 304.

FIG. 303.—Primitive nerve-fibres. A. A perfectly fresh tubule with a single dark outline. B. A tubule or fibre with a double contour from commencing post-mortem change. C. The changes further advanced, producing a varicose or beaded appearance. D. A tubule or fibre, the central part of which, in consequence of still further changes, has accumulated in separate portions within the sheath. (Wagner.)

FIG. 304.—Two nerve-fibres of sciatic nerve. A. Node of Ranvier. B. Axis-cylinders. C. Sheath of Schwann, with nuclei. × 300. (Klein and Noble Smith.)

The whole contents of the nerve-tubules are extremely soft, for when subjected to pressure they readily pass from one part of the tubular sheath to another, and often cause a bulging at the side of the membrane. They also readily escape, on pressure, from the extremities of the tubule, in the form of a grumous or granular material.

The *nucleated sheath of Schwann* is a pellucid membrane, forming the outer investment of the nerve-fibre. Within this delicate structureless membrane nuclei are seen at intervals, surrounded by a variable amount of protoplasm. The sheath is structureless, like the sarcolemma, and the nuclei appear to be within it: together with the protoplasm which surrounds them, they are the relics of embryonic cells, and from their resemblance to the muscle corpuscles of striated muscle, may be termed nerve-corpuscles.

(2.) The *medullary sheath* or *white substance of Schwann* is the part to which the peculiar white aspect of the cerebro-spinal nerves is principally due. It is a thick, fatty, semi-fluid substance, as we have seen, possessing a double contour. It is said to be made up of a fine reticulum (Stilling, Klein), in the meshes of which is embedded the bright fatty material.

According to M'Carthy, the medullary sheath is composed of small rods radiating from the axis-cylinder to the sheath of Schwann. Sometimes the whole space is occupied by these rods, whilst at other times the rods appear shortened, and compressed laterally into bundles embedded in some homogeneous substance.

(3.) The *axis-cylinder* consists of a large number of primitive *fibrillæ*. This is well shown in the cornea, where the axis-cylinders of nerves break up into minute fibrils which go to form terminal networks (see Cornea), and also in the spinal cord, where these fibrillæ form a large part of the grey matter. From various considerations such as its invariable presence and unbroken continuity in all nerves, though the primitive sheath or the medullary sheath may be absent, there can be little doubt that the axis-cylinder is the conductor of nerve-force, the other parts of the nerve having the subsidiary function of support and possibly of insulation.

At regular intervals in most medullated nerves, the nucleated sheath of Schwann possesses annular constrictions (nodes of Ranvier). At these points (Figs. 304, 305), the continuity of the medullary white substance is interrupted, and the primitive sheath comes into immediate contact with the axis-cylinder.

Size.—The size of the nerve-fibres varies, and the same fibres do not preserve the same diameter through their whole length, being largest in their course within the trunks and branches of the nerves, in which the majority measure from $\frac{1}{2000}$ to $\frac{1}{3000}$ of an inch in diameter. As they approach the brain or spinal cord, and generally also in the tissues in which they are distributed, they gradually become smaller. In the grey or vesicular substance of the brain or spinal cord, they generally do not measure more than from $\frac{1}{10000}$ to $\frac{1}{14000}$ of an inch.

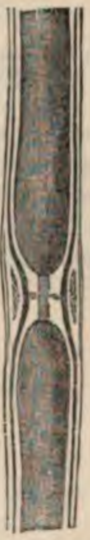


FIG. 305.—A node of Ranvier in a medullated nerve-fibre, viewed from above. The medullary sheath is interrupted, and the primitive sheath thickened. Copied from Axel Key and Retzius. × 750. (Klein and Noble Smith.)

(B.) **Non-Medullated Fibres.**—The fibres of the second kind (Fig. 306), which constitute the whole of the branches of the *olfactory* and *auditory* nerves, the principal part of the trunk and branches of the *sympathetic nerves*, and are mingled in various proportions in the cerebro-spinal nerves, differ from the preceding, chiefly in their fineness, being only about $\frac{1}{2}$ or $\frac{1}{3}$ as large in their course within the trunks and branches of the nerves; in the absence of the double contour; in their contents being apparently uniform; and in their having, when in bundles, a yellowish grey hue instead of the whiteness of the cerebro-spinal nerves. These peculiarities depend on their not possessing the outer layer of medullary nerve-substance; their contents being composed exclusively of the axis-cylinder. Yet, since many nerve-fibres may be found which appear intermediate in character between these two kinds, and since the large fibres, as they approach both their central and their peripheral end, gradually diminish in size, and assume many of the other characters of the fine fibres of the sympathetic system, it is not necessary to suppose that there is any material difference in the two kinds of fibres.

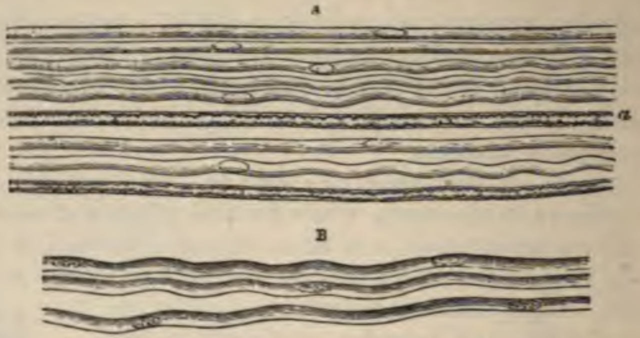


FIG. 306.—Grey, pale, or gelatinous nerve-fibres. A. From a branch of the olfactory nerve of the sheep; *a*, *a*, two dark-bordered or white fibres from the fifth pair, associated with the pale olfactory fibres. B. From the sympathetic nerve. × 450. (Max Schultze.)

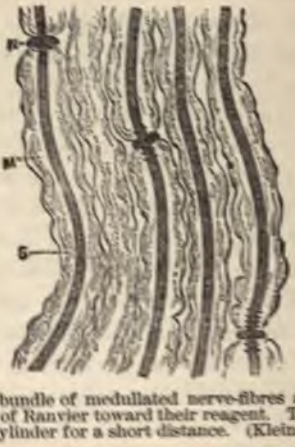


FIG. 307.—Several fibres of a bundle of medullated nerve-fibres acted upon by silver nitrate to show peculiar behavior of nodes of Ranvier toward their reagent. The silver has penetrated at the nodes, and has stained the axis-cylinder for a short distance. (Klein and Noble Smith.)

It is worthy of note, that in the fœtus, at an early period of development, all nerve-fibres are non-medullated.

Course.—Every nerve-fibre in its course proceeds uninterruptedly from its origin in a nerve-centre to near its destination, whether this be the periphery of the body, another nervous centre, or the same centre whence it issued.

Bundles of fibres run together in the nerve-trunk, but merely lie in apposition with each other; they do not unite: even when they anastomose, there is no union of fibres, but only an interchange of fibres between the anastomosing funiculi. Although each nerve-fibre is thus single and undivided through nearly its whole course, yet as it approaches the region in which it terminates, individual fibres break up into several subdivisions (Fig. 308) before their final ending. The medullated nerve-fibres, moreover, lose their medullary sheath before their final distribution, and acquire the characters more or less of non-medullated fibres.

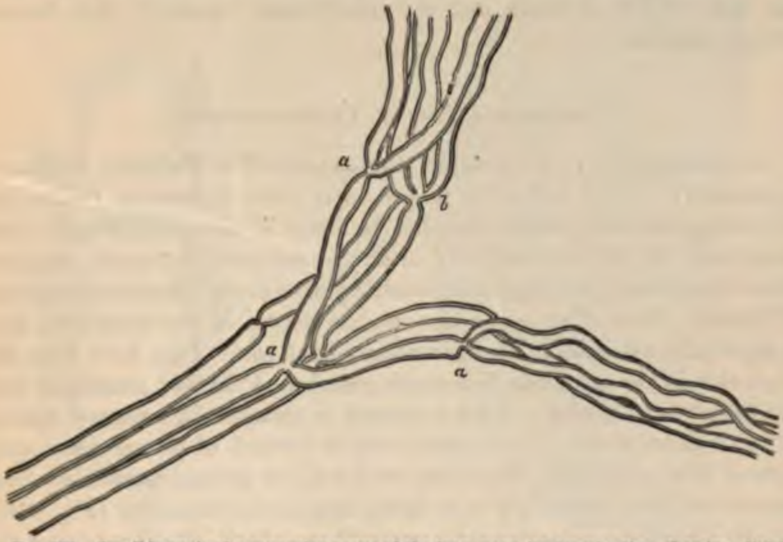


FIG. 308.—Small branch of a muscular nerve of the frog, near its termination, showing divisions of the fibres. *a*, into two; *b*, into three; × 350. (Kölliker.)

Plexuses.—At certain parts of their course, nerves form *plexuses*, in which they anastomose with each other, as in the case of the brachial and lumbar plexuses. The objects of such interchange of fibres are, (*a*), to give to each nerve passing off from the plexus, a wider connection with the spinal cord than it would have if it proceeded to its destination without such communication with other nerves. Thus, each nerve by the wideness of its connections, is less dependent on the integrity of any single portion, whether of nerve-centre or of nerve-trunk, from which it may spring. (*b*) Each part supplied from a plexus has wider relations with the nerve-centres, and more extensive sympathies; and, by means of the same arrangement, groups of muscles may be co-ordinated, every member of the group receiving motor filaments from the same parts of the nerve-centre. (*c*) Any given part, say a limb, is less dependent upon the integrity of any one nerve. (*d*) A plexus is frequently the means by which *centripetal* and *centrifugal* fibres are conveniently mingled for distribution, as in the case of the pneumogastric nerve, which receives motor filaments, near its origin, from the spinal accessory.

As medullated nerve-fibres approach their terminations they lose their medullary sheath, and consist then merely of axis-cylinder and primitive sheath. They then lose also the latter, and only the axis-cylinder is left, with here and there a nerve-corpuscle partly rolled around it. Finally, even this investment ceases, and the axis-cylinder breaks up into its elementary fibrillæ.

PERIPHERAL NERVE TERMINATIONS.

(a.) **Sensory.**—(1.) *Pacinian Corpuscles.*—The Pacinian bodies or corpuscles (Figs. 309 and 310), named after their discoverer Pacini, are little elongated oval bodies, situated on some of the cerebro-spinal and sympathetic nerves, especially the cutaneous nerves of the hands and feet; and on branches of the large sympathetic plexus about the abdominal aorta (Kölliker). They often occur also on the nerves of the mesentery, and are especially well seen in the mesentery of the cat. They have been observed also in the pancreas, lymphatic glands and thyroid glands, as well as in the penis of the cat. Each corpuscle is attached by a narrow pedicle to the nerve on which it is situated, and is formed of several concentric layers of fine membrane, consisting of a hyaline ground-membrane with connective-tissue fibres, each layer being lined by endothelium (Fig. 310); through its pedicle passes a single nerve-fibre, which, after traversing the several concentric layers and their immediate spaces, enters a central cavity, and, gradually losing its dark border, and becoming smaller, terminates at or near the distal end of the cavity, in a knob-like enlargement, or in a bifurcation. The enlargement commonly found at the end of the fibre, is said by Pacini to resemble a ganglion corpuscle; but this observation has not been confirmed. In some cases two nerves have been seen entering one Pacinian body, and in others a nerve after passing unaltered through one, has been observed to terminate in a second Pacinian corpuscle. The physiological import of these bodies is still obscure. Closely allied to Pacinian corpuscles, except that they are smaller and longer, with a row of nuclei around the central termination of the nerve in the core, are *corpuscles of Herbst*, which have been found chiefly in the tongues of ducks. The capsules are nearer together, and toward the centre the endothelial sheath appears to be absent.

(2.) *End-bulbs* are found in the conjunctiva, in the penis and clitoris, in the skin, and in tendon; each is composed of a medullated nerve-fibre which terminates in corpuscles of various shapes, with a capsule containing a transparent or striated mass, in the centre of which terminates the axis-cylinder of the nerve-fibre, the ending of which is somewhat clubbed (Fig. 230).

(3.) *Touch corpuscles* (Fig. 229) are found in the papillæ of the skin or among its epithelium; they may be simple or compound; when simple they are large and slightly flattened transparent nucleated ganglion cells enclosed in a capsule; when compound the capsule contains several small cells. The corpuscles of Grandry form another variety, and have been noticed in the beaks and tongues of birds. They consist of corpuscles oval or spherical, contained within a delicate nucleated sheath, and containing several cells, two or more compressed vertically. The cells are granular and transparent, with a nucleus. The nerve enters on one side, and laying aside its medullary sheath, terminates in or between the cells.

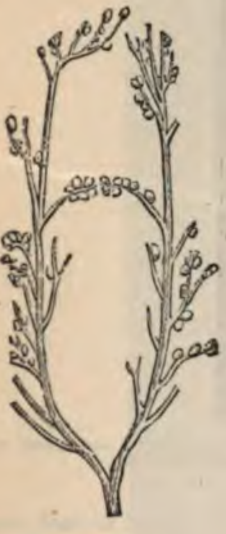


FIG. 309.

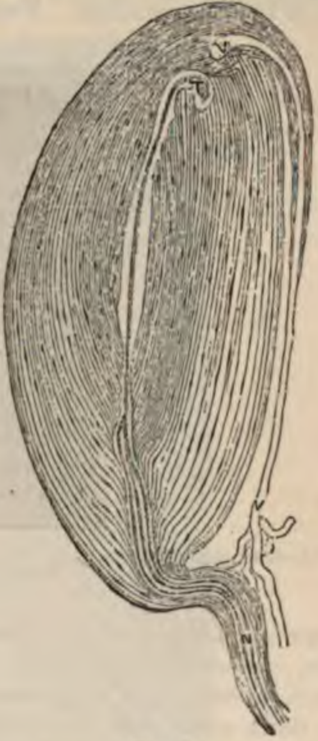


FIG. 310.

FIG. 309.—Extremities of a nerve of the finger with Pacinian corpuscles attached, about the natural size (adapted from Henle and Kölliker).

FIG. 310.—Pacinian corpuscle of the cat's mesentery. The stalk consists of a nerve-fibre (N) with its thick outer sheath. The peripheral capsules of the Pacinian corpuscle are continuous with the outer sheath of the stalk. The intermediary part becomes much narrower near the entrance of the axis-cylinder into the clear central mass. A hook-shaped termination with the end-bulb (T) is seen in the upper part. A blood-vessel (V) enters the Pacinian corpuscle, and approaches the end-bulb: it possesses a sheath which is the continuation of the peripheral capsules of the Pacinian corpuscle. × 100. (Klein and Noble Smith.)

(4.) In *plexuses,* as in the cornea, both sub-epithelial and also intra-epithelial.

(5.) In cells, as in the salivary glands (p. 228, Vol. I.), and in the special sense organs. To the latter, further allusion will be made in a future chapter.

(b.) **Motory.**—(1.) In *unstriped* muscle, the nerves first of all form a plexus, called the *ground plexus* (Arnold), corresponding to each group of muscle bundles; the plexus is made by the anastomosis of the primitive fibrils of the axis-cylinders. From the ground plexus, branches pass off, and again anastomosing, form plexuses which correspond to each muscle bundle,—*intermediary plexuses.* From these plexuses branches consisting of primitive fibrils pass in between the individual fibres and anastomose. These fibrils either send off finer branches, or terminate themselves in the nuclei of the muscle cells.

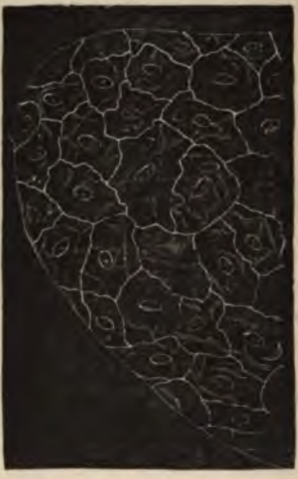


FIG. 311.—Summit of a Pacinian corpuscle of the human finger, showing the endothelial membranes lining the capsules. × 220. (Klein and Noble Smith.)

(2.) In *striped* muscle the nerves end in the so-called "*motorial end-plates,*" having first formed, as in the case of unstriped fibres, ground and intermediary plexuses. The nerves are, however, medullated, and when a branch of the intermediary plexus passes to enter a muscle-fibre, its primitive sheath becomes continuous with the sarcolemma, and the axis-cylinder forms a network of its fibrils on the surface of the fibre. This network lies embedded in a flattened granular mass containing nuclei of several kinds; this is the *motorial end-plate* (Fig. 312). In batrachia, besides end-plates, there is another way in which the nerves end in the muscle-fibres, viz., by rounded extremities, to which oblong nuclei are attached.

NERVE CELLS OR CORPUSCLES.

The *vesicular* nervous substance contains, as its name implies, *vesicles* or *corpuscles*, in addition to fibres; and a structure, thus composed of corpuscles and inter-communicating fibres, constitutes a *nerve-centre;* the chief nerve-centres being the grey matter of the brain and spinal cord, and the various *ganglia*. In the brain and spinal cord a fine stroma of *neuroglia* (p. 34, Vol. I.), extends throughout both the fibrous and vesicular nervous substance, and forms a supporting and investing framework for the whole.

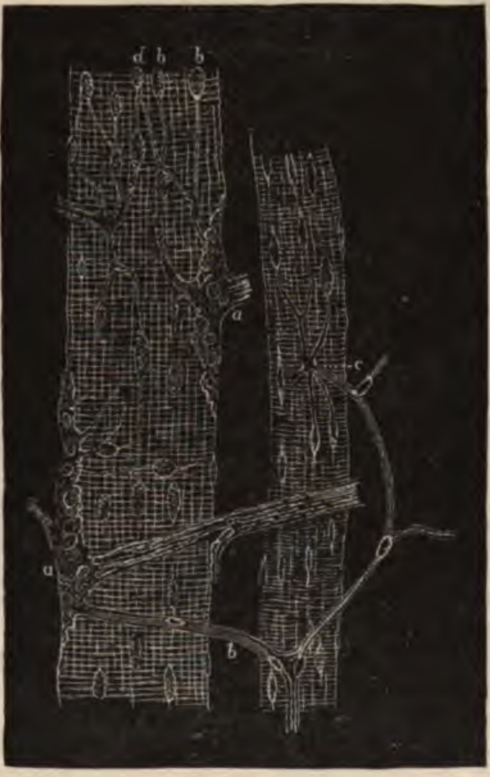


FIG. 312.—Two striped muscle-fibres of the hyoglossus of frog. *a*, Nerve end-plate; *b*, nerve fibres leaving the end-plate; *c*, nerve-fibres, terminating after dividing into branches; *d*, a nucleus in which two nerve-fibres anastomose. × 600. (Arndt.)

The nerve-corpuscles which give to the ganglia and to certain parts of the brain and spinal cord the peculiar greyish or reddish-grey aspect by which these parts are characterized, are large, nucleated cells, filled with a finely granular material, some of which is often dark like pigment:

the nucleus containing a nucleolus. Besides varying much in shape, partly in consequence of mutual pressure, they present such other varieties as make it probable either that there are two different kinds, or that, in the stages of their development, they pass through very different forms. Some of them are small, generally spherical or ovoid, and have a regular uninterrupted outline. These *simple* nerve-corpuscles are most numerous in the sympathetic ganglia; each is enclosed in a nucleated sheath. Others, which are called *caudate* or *stellate nerve-corpuscles* (Fig. 313), are larger, and have one, two, or more long processes issuing from them, the cells being called respectively *unipolar, bipolar,* or *multipolar;* which processes often divide and subdivide, and appear tubular, and filled with the same kind of granular material that is contained within the corpuscle. Of these processes some appear to taper to a point and terminate at a greater or less distance from the corpuscle; some appear to anastomose with similar offsets from other corpuscles; while others are continuous with nerve-fibres, the prolongation from the cell by degrees assuming the characters of the nerve-fibre with which it is continuous.

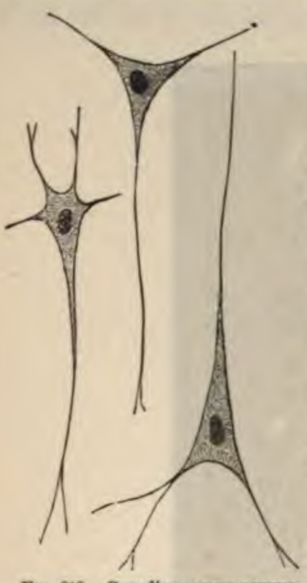


FIG. 313.—Ganglion nerve-corpuscles of different shapes. (Klein and Noble Smith.)

Ganglion-cells are each enclosed in a transparent membranous capsule similar in appearance to the nucleated sheath of Schwann in nerve-fibres: within this capsule is a layer of small flattened cells.

That process of a nerve-cell which becomes continuous with a nerve-fibre is always unbranched, as it leaves the cell. It at first has all the characters of an axis-cylinder, but soon acquires a medullary sheath, and then may be termed a nerve-fibre. This continuity of nerve-cells and fibres may be readily traced out in the anterior cornua of the grey matter of the spinal cord. In many large branched nerve-cells a distinctly fibrillated appearance is observable; the fibrillæ are probably continuous with those of the axis-cylinder of a nerve.

THE FUNCTIONS OF NERVE FIBRES.

It will be evident from the account of nervous action previously given (p. 45 *et seq.*, Vol. II.) that nerve-fibres are stimulated to act by anything which increases their irritability, but that they are incapable of originating of themselves the condition necessary for the manifestation of their own functions. When a cerebro-spinal nerve-fibre is irritated in the living body, as by pinching, or by heat, or by electrifying it, there is, under ordinary circumstances, one of two effects,—either there is pain, or there is twitching of one or more muscles to which the nerve distributes its fibres. From various considerations it is certain that pain is always the result of a change in the nerve-cells of the brain. Therefore, in such an experiment as that referred to, the irritation of the nerve-fibre seems to the experimenter to be *conducted* in one of two directions, *i.e.*, either to the brain (*central termination of the fibre*), when there is pain, or to a muscle (*peripheral termination*) when there is movement.

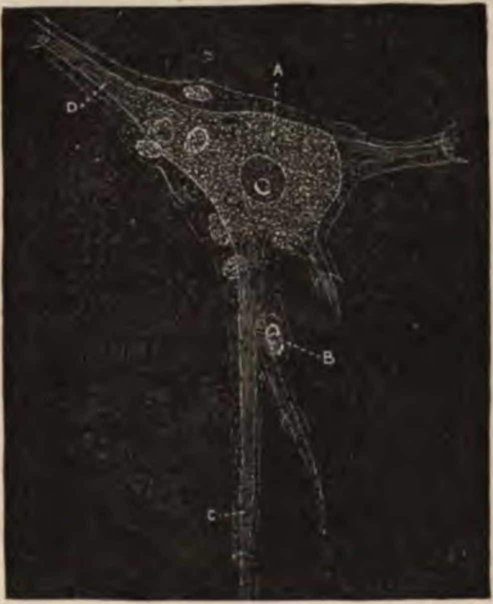


Fig. 314.—An isolated sympathetic ganglion cell of man, showing sheath with nucleated-cell lining, B. A. Ganglion-cell, with nucleus and neucleolus. C. Branched process. D. Unbranched process. Copied from Key and Retzius. × 750. (Klein and Noble Smith.)

The effect of this simple experiment is a type of what always occurs when nerve-fibres are engaged in the performance of their functions. The result of stimulating them, which roughly imitates what happens naturally in the body, is found to occur at one or other of their extremities, central or peripheral, never at both; and in accordance with this fact, and because, for any given nerve-fibre, the result is always the same, nerves are commonly classed as *sensory* or *motor*.

It may be well to state, in order to avoid confusion, that the apparent conduction in *both* directions, which seems to occur when a nerve, say the ulnar or median, is irritated, depends on the fact that both motor and sensory *fibres* are bound up together in the same *nerve-trunks*—an arrangement which, for medium-sized and large nerves, is the rule rather than the exception.

Conduction in Nerves.—A nerve when removed from the body will be found to conduct electrical impressions in either direction equally well, and microscopic examination fails to discover the slightest essential difference between motor and sensory nerve-fibres. The question, therefore, naturally arises, whether the conduction of a stimulus in the living body, in one direction only, is not rather apparent than real, the difference in the result being due to the different connections of the two kinds of nerve-fibres respectively at their extremities. In other words, when the stimulation of a nerve-fibre causes pain, the result is due to its *central* extremity being in connection with structures which alone can give rise to the sensation, while its *peripheral* extremity, although the stimulus is equally conducted to it, has no connection with a structure which can respond to the irritation in any manner sensible to the observer. So, when motion is the result of a like irritation, it is because the *peripheral* extremity of the nerve-fibre is in connection with muscles which will respond by contracting, while its *central* extremity, although equally stimulated, has no means of showing the fact by any evident result.

That this is the true explanation is made highly probable, not merely by the absense of any structural differences in the two kinds of nerve-fibre, but also by the fact, proved by direct experiment, that if a centripetal nerve (gustatory) be divided, and its central portion be made to unite with the distal portion of a divided motor nerve (hypoglossal) the effect of irritating the former after the parts have healed, is to excite contraction in the muscles supplied by the latter. (Philippeaux and Vulpian.)

Classification of Nerve-Fibres.—1. Centripetal, afferent, or, 2. Centrifugal, afferent, or motor. 3. Intercentral.

Centripetal or *afferent*, and *centrifugal* or *efferent*, are frequently employed in connection with nerve-fibres in lieu of the corresponding terms *sensory* and *motor*, because the result of stimulating a nerve of the former kind is not *always* the production of pain or other form of sensation, nor is motion the *invariable* result of stimulating the latter.

Conduction in *centripetal* nerves may cause (*a*) pain, or some other kind of sensation; or (*b*) reflex action; or (*c*) inhibition, or restraint of action.

Conduction in *centrifugal* nerves, may cause (*a*) contraction of muscle (p. 25, Vol. II.), (motor nerves); (*b*) it may influence nutrition (trophic nerves); or (*c*) may influence secretion (secretory nerves).

The term *intercentral* is applied to those nerve-fibres which connect more or less distinct nerve-centres, and may, therefore, be said to have no *peripheral* distribution, in the ordinary sense of the term.

It is a law of action in all nerve-fibres, and corresponds with the continuity and simplicity of their course, that an impression made on any fibre, is simply and uninterruptedly transmitted along it, without being imparted or diffused to any of the fibres lying near it. In other words, all nerve-fibres are mere *conductors* of impressions. Their adaptation to this purpose is, perhaps, due to the contents of each fibre being completely isolated from those of adjacent fibres by the membrane or sheath in which each is enclosed, and which acts, it may be supposed, just as silk or other non-conductors of electricity do, which, when covering a wire, prevent the electric condition of the wire from being conducted into the surrounding medium.

Velocity of Nerve-force.—The change which a stimulus sets upon a nerve, of the exact nature of which we are unacquainted, appears to travel along a nerve-fibre in both directions in the form of a wave. Nervous force travels along nerve-fibres with considerable velocity. Helmholtz and Baxt have estimated the average rate of conduction in human motor nerves at 111 feet (nearly 29 metres) per second; this result agreeing very closely with that previously obtained by Hirsch. Rutherford's observations agree with those of Von Wittich, that the rate of transmission in sensory nerves is about 140 feet per second.

Conduction in Sensory Nerves.—Centripetal nerves *appear* (p. 80, Vol. II.) able to convey impressions only from the parts in which they are distributed, toward the nerve-centre from which they arise, or to which they tend. Thus, when a sensitive nerve is divided, and irritation is applied to the end of the proximal portion, *i.e.*, of the portion still connected with the nervous centre, sensation is perceived, or a reflex action ensues; but, when the end of the distal portion of the divided nerve is irritated, no effect appears. When an impression is made upon any part of the course of a sensory nerve, the mind may perceive it as if it were made not only upon the point to which the stimulus is applied, but also upon all the points in which the fibres of the irritated nerve are distributed: in other words, the effect is the same as if the irritation were applied to the parts supplied by the branches of the nerve. When the whole trunk of the nerve is irritated, the sensation is felt at all the parts which receive branches from it; but when only individual portions of the trunk are irritated, the sensation is perceived at those parts only which are supplied by the several portions. Thus, if we compress the ulnar nerve where it lies at the inner side of the elbow-joint, behind the internal condyle, we have the sensation of "pins and needles," or of a shock, in the parts to which its fibres are distributed, namely, in the palm and back of the hand, and in the fifth and ulna half of the fourth finger. When stronger pressure is made, the sensations are felt in the fore-arm also; and if the mode and direction of the pressure be varied, the sensation is felt by turns in the fourth finger, in the fifth, and in the palm of the hand, or in the back of the hand, according as different fibres or fasciculi of fibres are more pressed upon than others.

Illustrations.—It is in accordance with this law, that when parts are deprived of sensibility by compression or division of the nerves supplying them, irritation of the portion of the nerve connected with the brain still excites sensations which are felt as if derived from the parts to which the peripheral extremities of the nerve-fibres are distributed. Thus, there are cases of paralysis in which the limbs are totally insensible to external stimuli, yet are the seat of most violent pain, resulting apparently from irritation of the sound part of the trunk of the nerve still in connection with the brain, or from irritation of those parts of the nervous centre from which the sensory nerve or nerves which supply the paralyzed limbs originate. An illustration of the same law is also afforded by the cases in which division of a nerve for the cure of neuralgic pain is found useless, and in which the pain continues or returns, though portions of the nerves be removed. In such cases, the disease is probably seated nearer the nervous centre than the part at which the division of the nerve is made, or it may be in the nervous centre itself. In the same way may be explained the fact, that when part of a limb has been removed by amputation, the remaining portions of the nerves may give rise to sensations which the mind refers to the lost part. When the stump is healed, the sensations which we are accustomed to have in a sound limb are still felt; and tingling and pains are referred to the parts that are lost, or to particular portions of them, as to single toes, to the sole of the foot, to the dorsum of the foot, etc.

It must not be assumed, as it often has been, that the mind has no power of discriminating the very point in the length of any nerve-fibre to which an irritation is applied. Even in the instances referred to, the mind perceives the pressure of a nerve at the point of pressure, as well as in the seeming sensations derived from the extremities of the fibres: and in stumps, pain is felt in the stump, as well as, seemingly, in the parts removed. It is not quite certain whether those sensations are due to conduction through the nerve fibres which are on their way to be distributed elsewhere, or through the sentient extremities of nerves which are themselves distributed to the many trunks of the nerves, the *nervi nervorum.* The latter is the more probable supposition.

When, in a part of the body which receives two sensory nerves, one is paralyzed, the other may or may not be inadequate to maintain the sensibility of the entire part; the extent to which the sensibility is preserved corresponding probably with the number of the fibres unaffected by the paralysis. There are instances in which the trunk of the chief sensory nerve supplied to a part having been divided, the sensibility of the part is still preserved by intercommunicating fibres from a neighboring nerve-trunk.

Conduction in the Nerves of Special Sense.—The laws of conduction in the *olfactory, optic, auditory, gustatory*—resemble in many aspects those of conduction in the nerves of common sensation, just described. Thus the effect is always *central;* stimulation of the trunk of the nerve produces the same effect as that of its extremities, and if the nerve be severed, it is the central and not the peripheral extremity which responds to irritation, although the sensation is referred to the periphery. There are, however, certain peculiarities in the effect. Thus the various stimuli, which might cause, through an ordinary sensitive nerve, the sense of pain, would, if applied to the optic nerve, cause a sensation as of flashes of light; if applied to the olfactory, there would be a sense as of something smelt. And so with the other two.

Hence the explanation of so-called *subjective* sensations. Irritation in the optic nerve, or the part of the brain from which it arises, may cause a patient to believe he sees flashes of light, and among the commonest troubles of the nerves of special sense, is the distressing noise in the head (*tinnitus aurium*), which depends on some unknown stimulation of the auditory nerve or centre quite unconnected with external sounds.

Conduction in Motor Nerves.—Conduction in motor nerves presents a remarkable contrast with the foregoing. Thus—the effect of applying a stimulus to the motor nerve is always noticeable, at the peripheral extremity, in the contraction of muscles supplied by it. If a motor nerve be severed, irritation of the distal portion causes contraction of muscle, but no effect whatever is produced by stimulating that part of the nerve which is still in direct connection with the nerve-centre.

Contractions are excited in all the muscles supplied by the branches given off by the nerve below the point irritated, and in those muscles alone: the muscles supplied by the branches which come off from the nerve at a higher point than that irritated, are not directly excited to contraction. And it is from the same fact that, when a motor nerve enters a plexus and contributes with other nerves to the formation of a nervous trunk proceeding from the plexus, it does not impart motor power to the whole of that trunk, but only retains it isolated in the fibres which form its continuation in the branches of that trunk.

Functions of Nerve-Centres.

The functions of nerve-centres may be classified as follows:—1. *Conduction.* 2. *Transference.* 3. *Reflection.* 4. *Automatism.* 5. *Augmentation.* 6. *Inhibition.*

1. **Conduction.**—Conduction in or through nerve-centres may be thus simply illustrated. The food in a given portion of the intestines, acting as a stimulus, produces a certain impression on the nerves in the mucous membrane, which impression is conveyed through them to the adjacent ganglia of the sympathetic. In ordinary cases, the consequence of such an impression on the ganglia is the movement by reflex action (p. 85, Vol. II.) of the muscular coat of that and the adjacent part of the canal. But if irritant substances be mingled with the food, the sharper stimulus produces a stronger impression, and this is *conducted*

through the nearest ganglia to others more and more distant; and, from all these, reflex motor impulses issuing, excite a wide-extended and more forcible action of the intestines. Or even through the sympathetic ganglia, the impression may be further conducted to the ganglia of the spinal nerves, and through them to the spinal cord, whence may issue motor impulses to the abdominal and other muscles, producing cramp. And yet further, the same morbid impression may be conducted through the spinal cord to the brain, where it may be *felt*. In the opposite direction, mental influence may be conducted from the brain through a succession of nervous centres—the spinal cord and ganglia, and one or more ganglia of the sympathetic—to produce the influence of the mind on the digestive and other organs; altering both the quantity and quality of their secretions.

2. **Transference.**—It has been previously stated that impressions conveyed by any centripetal nerve-fibre travel uninterruptedly throughout its whole length, and are not communicated to adjacent fibres.

When such an impression, however, reaches a nerve-centre, it may seem to be communicated to another fibre or fibres: as pain or some other kind of sensation may be felt in a part different altogether from that from which, so to speak, the stimulus started. Thus, in disease of the hip, there may be pain in the knee. This apparent change of place of a sensation to a part to which it would not seem properly to belong is termed transference.

The transference of impressions may be illustrated by the fact just referred to,—the pain in the knee, which is a common sign of disease of the hip. In this case the impression made by the disease on the nerves of the hip-joint is conveyed to the spinal cord; there it is *transferred* to the central ends or connections of the nerve-fibres which are distributed about the knee. Through these the transferred impression is conducted to the brain, which, referring the sensation to the part from which it usually through these fibres receives impressions, feels as if the disease and the source of pain were in the knee. At the same time that it is transferred, the primary impression may be also conducted to the brain; and in this case the pain is felt in both the hip and the knee. And so, in whatever part of the respiratory organs an irritation may be seated, the impression it produces, being conducted to the medulla oblongata, is transferred to the central connections of the nerves of the larynx; and thence, being conducted as in the last case to the brain, the latter perceives the peculiar sense of tickling in the glottis, which excites the act of coughing. Or again, when the sun's light falls strongly on the eye, a tickling may be felt in the nose, exciting sneezing.

A variety of transference which may be termed radiation of impressions is shown when an impression received by a nervous centre is diffused to many other parts in the same centre, and produces sensations extending far beyond the part from which the primary impression was derived. Hence, as in the former cases, result various kinds of what have been denominated sympathetic sensations. Sometimes such sensations are referred to almost every part of the body: as in the shock and tingling of the skin produced by some startling noise. Sometimes only the parts immediately surrounding the point first irritated participate in the effects of the irritation; thus the aching of a tooth may be accompanied by pain in the adjoining teeth, and in all the surrounding parts of the face; the explanation of such a case being, that the irritation conveyed to the brain by the nerve-fibres of the diseased tooth is *radiated* to the central ends of adjoining fibres, and that the mind perceives this secondary impression as if it were derived from the peripheral ends of the fibres.

3. **Reflection.**—In the cases of transference of nerve-force just described, it has been said that all that need be assumed is a communication of the excited condition of an afferent nerve to other parts of its nerve-centre than that from which it takes its origin. In the case of *reflection*, on the other hand, the stimulus having been conveyed to a nerve-centre by a centripetal nerve, is conducted away again by a centrifugal nerve, and effects some change—motor, secretory or nutritive, at the peripheral extremity of the latter—the difference in effect depending on the variety of centrifugal nerve secondarily affected. As in transference, the reflection may take place from a certain limited set of centripetal nerves to a corresponding and related set of centrifugal nerves; as when in consequence of the impression of light on the retina, the iris contracts, but no other muscle moves. Or the reflection may extend to widely different parts: as when an irritation in the larynx brings all the muscles engaged in expiration into coincident movement. Reflex movements, occurring quite independently of sensation, are generally called *excito-motor;* those which are guided or accompanied by sensation, but not to the extent of a distinct perception or intellectual process are termed *sensori-motor.*

Laws of Reflex Action.—(*a*) For the manifestation of every reflex action, these things are necessary: (1), one or more perfect *centripetal* nerve-fibres, to convey an impression; (2), a *nervous centre* for its reception, and by which it may be reflected; (3), one or more *centrifugal* nerve-fibres, along which the impression may be conducted to (4), the muscular or other tissue by which the effect is manifested (p. 80, Vol. II.). In the absence of any one of these conditions, a proper reflex action could not take place; and whenever, for example, impressions made by external stimuli on sensory nerves give rise to motions, these are never the result of the direct reaction of the sensory and motor fibres of the nerves on each other; in all such cases the impression is conveyed by the afferent fibres to a nerve-centre, and is therein communicated to the motor fibres.

(*b*) All reflex actions are essentially involuntary, though most of them admit of being modified, controlled, or prevented by a voluntary effort.

(*c*) Reflex actions performed in health have, for the most part, a distinct purpose, and are adapted to secure some end desirable for the well-being of the body; but, in disease, many of them are irregular and purposeless. As an illustration of the first point, may be mentioned movements of the digestive canal, the respiratory movements, and the contraction of the eyelids and the pupil to exclude many rays of light, when the retina is exposed to a bright glare. These and all other normal reflex acts afford also examples of the mode in which the nervous centres *combine* and arrange co-ordinately the actions of the nerve-fibres, so that many muscles may act together for the common end. Another instance of the same kind is furnished by the spasmodic contractions of the glottis on the contact of carbonic acid, or any foreign substance, with the surface of the epiglottis or larynx. Examples of the purposeless irregular nature of morbid reflex action are seen in the convulsive movements of epilepsy, and in the spasms of tetanus and hydrophobia.

(*d*) Reflex muscular acts are often more sustained than those produced by the direct stimulus of muscular nerves. The irritation of a muscular organ, or its motor nerve, produces contraction lasting only so long as the irritation continues; but irritation applied to a nervous centre through one of its centripetal nerves, may excite reflex and harmonious contractions, which last some time after the withdrawal of the stimulus (Volkmann).

Classification of Reflex Actions.—Reflex actions may be classified as follows (Kuss):—1. Those in which both the centripetal and centrifugal nerves concerned are *cerebro-spinal*, *e.g.*, deglutition, sneezing, coughing, and, in pathological conditions, tetanus, epilepsy. 2. Those in which the centripetal nerve is *cerebro-spinal*, and the centrifugal is *sympathetic*, most often vaso-motor, *e.g.*, secretion of saliva, or gastric juice, blushing or pallor of the skin. 3. Those in which the centripetal nerve is of the sympathetic system, and the centrifugal is *cerebro-spinal*. The majority of these are pathological, as in the case of convulsions produced by intestinal worms, or hysterical convulsions. 4. Those in which both centripetal and centrifugal nerves are of the *sympathetic* system: as, for example, the obscure actions which preside over the secretion of the intestinal fluids, those which unite the various generative functions and many pathological phenomena.

Relations between the Stimulus and the Resulting Reflex Action.—Certain rules showing the relation between the resulting reflex action and the stimulus have been drawn up by Pflüger, as follows:—

1. [illegible].—A slight irritation of sensory nerves is reflected along the motor nerves of the same region. Thus, if the skin of a frog's foot be tickled on the *right* side, the *right* leg is drawn up.

2. *Law of symmetrical reflection.*—A stronger irritation is reflected, not only on one side, but also along the corresponding motor nerves of the opposite side. Thus, if the spinal cord of a man has been severed by a stab in the back, when one foot is tickled *both* legs will be drawn up.

3. *Law of intensity.*—In the above case, the contractions will be more violent on the side irritated.

4. *Law of radiation.*—If the irritation (afferent impulse) increases, it is reflected along the motor nerves which spring from points higher up the spinal cord, till at length all the muscles of the body are thrown into action.

Simple and Co-ordinated Reflex Actions.—In the simplest form of reflex action a single nerve cell with an afferent and an efferent fibre is concerned, but in the majority of actual actions a number of cells are probably concerned, and the impression is as it were distributed among them, and they act in concert or co-ordination. This co-ordinating power belongs to nerve centres.

Primary and Secondary or Acquired Reflex Actions.—We must carefully distinguish between such reflex actions which may be termed *primary*, and those which are *secondary* or *acquired*. As examples of the former class we may cite sucking, contraction of the pupil, drawing up the legs when the toes are tickled, and many others which are performed as perfectly by the infant as by the adult.

The large class of *secondary* reflex actions consists of acts which require for their first performance and many subsequent repetitions, an effort of will, but which by constant repetition are habitually though not necessarily performed, mechanically, *i.e.*, without the intervention of consciousness and volition. As instances we may take reading, writing, walking, etc.

In endeavoring to conceive how such complicated actions can be performed without consciousness and will, we must suppose that in the first instance the will directs the nerve-force along certain channels causing the performance of certain acts, *e.g.*, the various movements of flexion and extension involved in walking. After a time, by constant repetition, these routes become, to use a metaphor, well *worn:* there is, as it were, a beaten track along which the nerve-force travels with much greater ease than formerly: so much so that a slight stimulus, such as the pressure of the foot on the ground, is sufficient to start and keep going indefinitely the complex reflex actions of walking during entire mental abstraction, or even during sleep. In such acts as reading, writing, and the like, it would appear as if the will set the necessary reflex machinery going, and that the reflex actions go on uninterruptedly until again interfered with by the will.

Without this capacity possessed by the nervous system of "organizing conscious actions into more or less unconscious ones," education or training would be impossible. A most important part of the process by which these acquired reflex actions come to be performed automatically consists in what is termed *association*. If two acts be at first performed voluntarily in succession, and this succession is often repeated, the performance of the first is at once followed mechanically by the second. Instances of this "force of habit" must be within the daily experience of every one.

Of course it is only such actions as have become entirely reflex that can be performed during complete unconsciousness, as in sleep. Cases of somnambulism are of course familiar to every one, and authentic instances are on record of persons writing and even playing the piano during sleep.

(c.) **Automatism.** To nerve centres, it is said, belongs the property of originating nerve impulses, as well as of receiving them and conducting and reflecting them.

The term [illegible] is employed to indicate the origination of nervous impulses in nerve centres, and their conduction therefrom, independently of the reception of a stimulus from another part. It is impossible, in the present state of our knowledge, to say definitely what actions in the body are really in this sense automatic. An example of automatic action has been already referred to, viz., that of the respiratory [illegible] the apparently best examples of automatism are found, [illegible] of the cerebrum, which will be presently considered.

[illegible] **Augmentation and Inhibition.**—Nerve cells not only [illegible] nerve impulses, and also in some cases even originate [illegible] are also capable of increasing the impulse, and [illegible] and when a nerve centre is in [illegible] increased or diminished (*inhibi-* [illegible] whatever way the centre [illegible] means of previous afferent [illegible] is capable of being inhibited or [illegible] vaso-motor centre, before [illegible] exerted from the [illegible] action even of partially [illegible]

[illegible] SYSTEM

[illegible] system includes that of [illegible] the several Nerves [illegible]

[illegible] Spinal Cord.—The Brain and [illegible] Dura Mater.

[illegible] membrane comsed of bundles of connective tissue which cross at various angles, and whose interstices branched connective-tissue corpuscles lie: it is lined a thin elastic membrane, and on the inner surface, and, where it is not

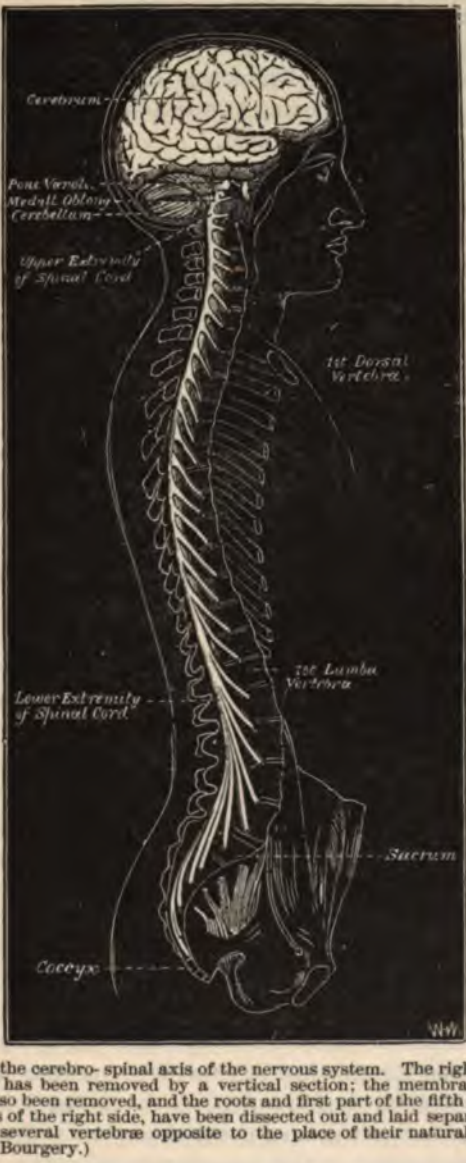


FIG. 315.—View of the cerebro- spinal axis of the nervous system. The right half of the cranium d trunk of the body has been removed by a vertical section; the membranes of the brain and nal marrow have also been removed, and the roots and first part of the fifth and ninth cranial, and all the spinal nerves of the right side, have been dissected out and laid separately on the wall of skull and on the several vertebræ opposite to the place of their natural exit from the cranio-nal cavity. (After Bourgery.)

herent to the bone, on the outer surface also, is a layer of endothelial lls very similar to those found in serous membranes. (2.) The *Arach-*

noid is a much more delicate membrane very similar in structure to the dura mater, and lined on its outer or free surface by an endothelial membrane. (3.) The *Pia Mater* consists of two chief layers between which numerous blood-vessels ramify. Between the arachnoid and pia mater is a network of fibrous-tissue trabeculæ sheathed with endothelial cells: these sub-arachnoid trabeculæ divide up the sub-arachnoid space into a number of irregular sinuses. There are some similar trabeculæ, but much fewer in number, traversing the sub-dural space, *i.e.*, the space between the dura mater and arachnoid.

"*Pacchionian*" bodies are growths from the sub-arachnoid network of connective-tissue trabeculæ which project through small holes in the inner layers of the dura mater into the venous sinuses of that membrane. The venous sinuses of the dura mater have been injected from the sub-arachnoidal space through the intermediation of these villous outgrowths known as "*Pacchionian* bodies."

THE SPINAL CORD AND ITS NERVES.

The Spinal cord is a cylindriform column of nerve-substance connected above with the brain through the medium of the medulla oblongata, and terminating below, about the lower border of the first lumbar vertebra, in a slender filament of grey substance, the *filum terminale*, which lies in the midst of the roots of many nerves forming the *cauda equina*.

Structure.—The cord is composed of white and grey nervous substance, of which the former is situated externally, and constitutes its chief portion, while the latter occupies its central or axial portion, and is so arranged, that on the surface of a transverse section of the cord it appears like two somewhat crescentic masses connected together by a narrower portion or isthmus (Fig. 318). Passing through the centre of this isthmus in a longitudinal direction is a minute canal (central canal), which is continued through the whole length of the cord, and opens above into the space at the back of medulla oblongata and pons Varolii, called the fourth ventricle. It is lined by a layer of columnar ciliated epithelium.

The spinal cord consists of two exactly symmetrical halves separated anteriorly and posteriorly by vertical *fissures* (the posterior fissure being deeper, but less wide and distinct than the anterior), and united in the middle by nervous matter which is usually described as forming two commissures—an *anterior* commissure, in front of the central canal, consisting of medullated nerve fibres, and a *posterior* commissure behind the central canal, consisting also of medullated nerve-fibres, but with more neuroglia, which gives the grey aspect to this commissure (Fig. 316, B). Each half of the spinal cord is marked on the sides (obscurely at the lower part, but distinctly above) by two longitudinal furrows, which divide it into three portions, columns, or tracts, an *anterior, lateral,* and *posterior.* From the groove between the anterior and lateral columns spring the *anterior roots* of the spinal nerves (B and C, 5); and just in front of the groove between the lateral and posterior column arise the *posterior roots* of the same (B, 6): a pair of roots on each side corresponding to each vertebra (Fig. 317).

White matter.—The white matter of the cord is made up of medullated nerve fibres, of various sizes, arranged longitudinally around the cord under the pia mater and passing in to support the individual fibres in the delicate connective tissue or *neuroglia* made up of a very fine reticulum, with both small cells almost filled up by nuclei and stellate, branching corpuscles.

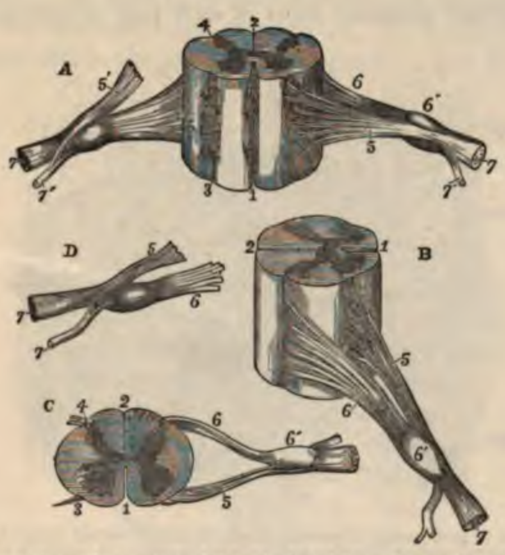


FIG. 316.—Different views of a portion of the spinal cord from the cervical region, with the roots of the nerves (slightly enlarged). In A, the anterior surface of the specimen is shown; the anterior nerve-root of its right side being divided; in B, a view of the right side is given; in C, the upper surface is shown; in D, the nerve-roots and ganglion are shown from below. 1. The anterior median fissure; 2, posterior median fissure; 3, anterior lateral depression, over which the anterior nerve-roots are seen to spread; 4, posterior lateral groove, into which the posterior roots are seen to sink; 5, anterior roots passing the ganglion; 5′, in A, the anterior root divided; 6, the posterior roots, the fibres of which pass into the ganglion 6′; 7, the united or compound nerve; 7′, the posterior primary branch, seen in A and D to be derived in part from the anterior and in part from the posterior root. (Allen Thomson.)

Size.—The general rule respecting the size of different parts of the cord appears to be, that the size of each part bears a direct proportion to the size and number of nerve-roots given off from itself, and has but little relation to the size or number of those given off below it. Thus the cord is very large in the middle and lower part of its cervical portion, whence arise the large nerve-roots for the formation of the brachial plexuses and the supply of the upper extremities, and again enlarges at the lowest part of its dorsal portion and the upper part of its lumbar, at the origins of the large nerves which, after forming the lumbar and sacral plexuses, are distributed to the lower extremities. The chief cause of the greater size at these parts of the spinal cord is increase in the quantity of grey matter; for there seems reason to believe that the white or fibrous part of the cord becomes gradually and progressively larger from below upward, doubtless from the addition of a certain number of upward passing fibres from each pair of nerves.

From careful estimates of the number of nerve-fibres in a transverse section of the cord toward its upper end, and the number entering it by the anterior and posterior roots of each pair of nerves, it has been shown that in the human spinal cord not more than half of the total number of nerve-fibres entering the cord through all the spinal nerves are contained in a transverse section near its upper end. It is obvious, therefore, that at least half of the nerve-fibres entering it must terminate in the cord itself.

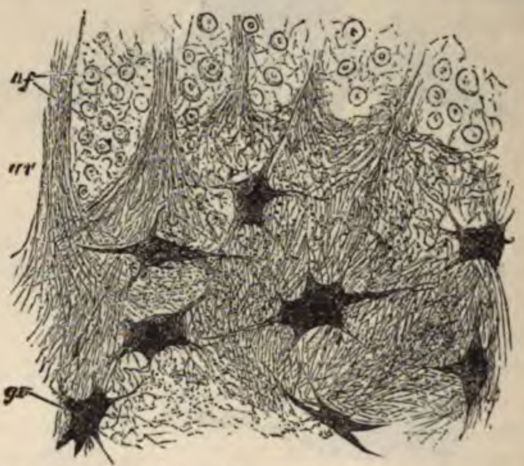


FIG. 317.—Section of grey matter of anterior cornu of a calf's spinal cord; *n f*, nerve-fibres of white matter in transverse section, showing axis-cylinder in centre of each; *a r*, anterior roots of spinal nerve passing out though white matter; *g c*, large stellate nerve-cells with nuclei; they are seen imbedded in neuroglia. (Schofield.)

Grey matter.—The grey matter of the cord consists essentially of an extremely delicate network of the primitive fibrillæ of axis-cylinders, and which are derived from the ramification of multipolar ganglion cells of very large size, containing large round nuclei with nucleoli. This fine plexus is called *Gerlach's network*, and is mingled with the meshes of neuroglia, which in some parts is chiefly fibrillated, in others mainly granular and punctiform. The neuroglia is prolonged from the surface into the tip of the posterior cornu of grey matter and forms a jelly-like transparent substance, which when hardened is found to be reticular, and is called the *substantia gelatinosa* of Rolando.

The multipolar cells are either scattered singly or arranged in groups, of which the following are to be distinguished:—(*a.*) In the *anterior cornu.* The groups found in the anterior cornu are generally two—one at the lateral part near the lateral column, and the other at the tip of the cornu in the middle line—sometimes, as in the lumbar enlargement, there is a third group more posterior. The cells of the anterior group are the largest. Into many of these cells the fibres of the anterior motor nerve-roots can be distinctly traced. (*b.*) In the *tractus intermedio-lateralis.* A group of nerve-cells midway between the anterior and posterior cornua, near the external surface of the grey matter. It is especially developed in the dorsal and also in the upper cervical region. (*c.*) In the *posterior vesicular columns* of Lockhart Clark. These are found in the posterior cornua of grey matter toward the inner surface, extending from the cervical enlargement to the third lumbar nerves (Fig. 318, *c*). (*d.*) Smaller cells are scattered throughout the grey matter, but are found chiefly at the tip (caput cornu) of the posterior cornu, in a finely granular basis, and among the posterior root fibres (*substantia gelatinosa cinerea* of Rolando).

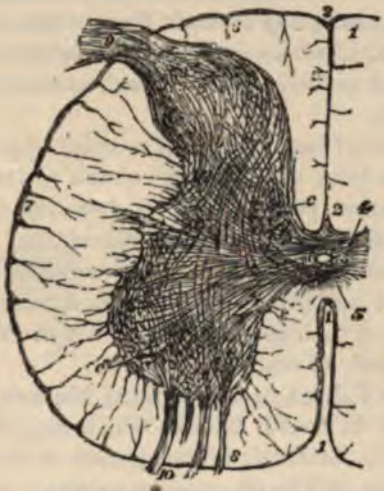


FIG. 318.—Transverse section of half the spinal cord in the lumbar enlargement (semi-diagrammatic). 1. Anterior median fissure; 2, posterior median fissure; 3, central canal lined with epithelium; 4, posterior commissure; 5, anterior commissure; 6, posterior column; 7, lateral column; 8, anterior column. The white substance is traversed by radiating trabeculæ of pia mater. 9. Fasciculus of posterior nerve-root entering in one bundle; 10, fasciculi of anterior roots entering in four spreading bundles of fibres: *b*, in the cervix cornu, decussating fibres from the nerve-roots and posterior commissure; *c*, posterior vesicular columns of Lockhart Clarke. About half way between the central canal and 7 are seen the group of nerve-cells forming the tractus intermedio-lateralis; *e*, *e*, fibres of anterior roots; *e′*, fibres of anterior roots which decussate in anterior commissure. (Allen Thomson.) × 6.

The nerve-cells are connected by their processes immediately with the axis-cylinder of the fibres of the anterior or motor nerve-roots: whereas the nerve-cells of the posterior roots are connected with nerve-fibres, not directly, but only through the intermediation of Gerlach's nerve-network, in which their branching processes lose themselves.

Spinal Nerves.—The spinal nerves consist of thirty-one pairs, issuing from the sides of the whole length of the cord, their number corresponding with the intervertebral foramina through which they pass. Each nerve arises by two roots, an anterior and posterior, the latter being the larger. The roots emerge through separate apertures of the sheath of dura mater surrounding the cord; and directly after their emergence, where the roots lie in the intervertebral foramen, a ganglion is found on the posterior root. The anterior root lies in contact with the anterior surface of the ganglion, but none of its fibres intermingle with those in the ganglion (5, Fig. 316). But immediately beyond the ganglion the two roots coalesce, and by the mingling of their fibres form a compound or mixed spinal nerve, which, after issuing from the intervertebral canal, divides into an anterior and posterior branch, each containing fibres from both the roots (Fig. 316).

The anterior root of each spinal nerve arises by numerous separate and converging bundles from the anterior column of the cord; the posterior root by more numerous parallel bundles, from the posterior column, or, rather, from the posterior part of the lateral column (Fig. 318), for if a fissure be directed inward from the groove between the middle and posterior columns, the posterior roots will remain attached to the former. The anterior roots of each spinal nerve consist of *centrifugal* fibres; the posterior as exclusively of *centripetal* fibres.

Course of the Fibres of the Spinal Nerves.—(*a*) The *Anterior roots* enter the cord in several bundles which may be called:—(1) Internal; (2) Middle; (3) External; all being more or less connected with the groups of multipolar cells in the anterior cornua. 1. The *internal* fibres are partly connected with internal group of nerve cells of anterior cornu of the same side; but some fibres pass over, through anterior commissure, to end in the anterior cornu of opposite side, probably in internal group of cells. 2. The *middle* fibres are partly in connection with the lateral group of cells in anterior cornu, and in part, pass backward to posterior cornu, having no connection with cells. 3. The *external* fibres are partly in connection with the lateral group of cells in the anterior cornu, but some fibres proceed direct into the lateral column without connection with cells and pass upward in it.

(*b*) The *Posterior roots* enter the posterior cornu in two chief bundles, either at the tip, through or round the substantia gelatinosa, or by the inner side. The former enter the grey matter at once, and as a rule, turn upward or downward for a certain distance and then pass horizontally, some fibres reach the anterior cornua, passing at once horizontally; and the others, the opposite side, through the posterior grey commissure. Of those which enter by the inner side of the cornua the majority pass up (or down) in the white substance of the posterior columns, and enter the grey matter at various heights at the base of the posterior cornu, perhaps some pass directly upward without entering the grey matter. Those that enter the grey matter pass in various directions, some to join the lateral cells in the anterior cornu, some join the cells in the posterior vesicular column, and some pass across to the other side of the cord in the anterior commissure, whilst others become again longitudinal in the grey matter.

It should be here mentioned that the cells in the posterior vesicular column are connected with medullated fibres which pass horizontally to the white matter of the lateral columns and there become longitudinal.

Course of the fibres in the cord. The nerve fibres which form the white matter of the cord are nearly all longitudinal fibres. It is, however, a matter of great difficulty to trace these fibres by mere dissection, and so some other methods must be adopted. One method is based upon the fact that nerve fibres undergo degeneration when they are cut off from the centre with which they are connected, or when the parts to which they are distributed are removed, as in amputation of a limb; and information as to the course of the fibres has been obtained by tracing the course of these degenerated tracts. The second method consists in observing the development of the various tracts; some have their medullary substance later than others, and are to be distinguished by their more grey appearance. The chief tracts which have been made out are the following:—(1) *The direct pyramidal tract* (Fig. 319 *d.p.t.*), a comparatively small portion of the inner part of the anterior columns, which is traceable from the anterior pyramids of the medulla to the mid-dorsal region of the spinal cord. It consists of the fibres of the pyramids which do not undergo decussation in the medulla. There is reason for believing, however, that these fibres of the direct pyramidal tract undergo decussation throughout their course, and fibres pass over through the anterior commissure to join the lateral pyramidal tract (*vide infra*); (2) the *Crossed pyramidal tract* (Fig. 319, *c.p.t.*) can be traced from the anterior pyramids

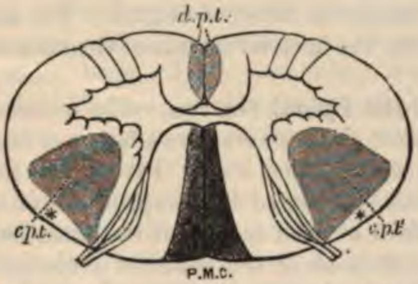


FIG. 319.—Diagram of the spinal cord at the lower cervical region to show the track of fibres; *d. p. t.*, direct pyramidal tract; *c. p. t.*, crossed pyramidal tract; * direct cerebellar tract; P. M. C., posterior medium column. (Gowers.)

of the medulla, and consists of fibres which decussate in the anterior fissure and pass downward in the lateral columns near the posterior cornu of the grey matter to the lower end of the cord; (3) *Direct cerebellar tract* (Fig. 319), which corresponds to the peripheral portion of the posterior lateral column between the crossed pyramidal tract and the edge of the cord, can be traced up directly to the cerebellum and down to the mid-lumbar region; (4). *Posterior medium column*, or *Fasciculus of Goll*, is found on either side of the posterior commissure, and is traceable upward as the fasciculus gracilis of the medulla, the fibres are connected with the cells of the posterior vesicular column. It is traceable downward to the mid-dorsal region. As regards the remaining part of the cord unoccupied by the above tracts little can be said. The portion of the posterior column between the posterior median column and the posterior roots of the spinal nerves, known as *fasciculus cuneatus* or *Burdach's column*, is composed of fibres of the posterior roots on their way to enter the grey substance at different heights. The antero-lateral column contains fibres from the anterior cornua of the same as well as of the opposite side.

Functions of the Spinal Nerves.—The anterior spinal nerve-roots are efferent or motor: the posterior are afferent or sensory (Sir. C. Bell). The fact is proved in various ways. Division of the anterior roots of one or more nerves is followed by complete loss of motion in the parts supplied by the fibres of such roots; but the sensation of the same parts remains perfect. Division of the posterior roots destroys the sensibility of the parts supplied by their fibres, while the power of motion continues unimpaired. Moreover, irritation of the ends of the distal portions of the divided anterior roots of a nerve excites muscular movements; irritation of the ends of the proximal portions, which are still in connection of the cord, is followed by no appreciable effect. Irritation of the distal portions of the divided posterior roots, on the other hand, produces no muscular movements and no manifestations of pain; for, as already stated, sensory nerves convey impressions only toward the nervous centres: but irritation of the proximal portions of these roots elicits signs of intense suffering. Occasionally, under this last irritation, muscular movements also ensue; but these are either voluntary, or the result of the irritation being reflected from the sensory to the motor fibres. Occasionally, too, irritation of the distal ends of divided anterior roots elicits signs of pain, as well as producing muscular movements: the pain thus excited is probably the result either of *cramp* or of so-called recurrent sensibility (Brown-Séquard).

Recurrent Sensibility.—If the anterior root of a spinal nerve be divided and the peripheral end be irritated, not only movements of the muscles supplied by the nerve take place, but also of other muscles, indicative of pain. If the main trunk of the nerve (after the coalescence of the roots beyond the ganglion) be divided, and the anterior root be irritated as before, the general signs of pain still remain, although the contraction of the muscles does not occur. The signs of pain disappear when the posterior root is divided. From these experiments it is believed that the stimulus passes down the anterior root to the mixed nerve and returns to the central nervous system through the posterior root by means of certain sensory fibres from the posterior root, which loop back into the anterior root, before continuing their course into the mixed nerve-trunk.

Functions of the Ganglia on Posterior Roots.—The ganglia act as centres for the nutrition of the nerves, since when the nerves are severed from connection with the ganglia, the parts of the nerves so severed degenerate, whilst the parts which remain in connection with them do not.

FUNCTIONS OF THE SPINAL CORD.

The power of the spinal cord, as a nerve-centre, may be arranged under the heads of (1) Conduction; (2) Transference; (3) Reflex action.

(1) *Conduction.*—The functions of the spinal cord in relation to *conduction* may be best remembered by considering its anatomical connections with other parts of the body. From these it is evident that, with the exception of some few filaments of the sympathetic, there is no way by which nerve-impulses can be conveyed from the trunk and extremities to the brain or *vice versâ*, other than that formed by the spinal cord. Through it, the impressions made upon the peripheral extremities or other parts of the spinal sensory nerves are conducted to the brain, where alone they can be *perceived*. Through it, also, the stimulus of the will, conducted from the brain, is capable of exciting the action of the muscles supplied from it with motor nerves. And for all these conductions of impressions to and fro between the brain and the spinal nerves, the perfect state of the cord is necessary; for when any part of it is destroyed, and its communication with the brain is interrupted, impressions on the sensory nerves given off from it below the seat of injury, cease to be propagated to the brain, and the brain loses the power of voluntarily exciting the motor nerves proceeding from the portion of cord isolated from it. Illustrations of this are furnished by various examples of paralysis, but by none better than by the common paraplegia, or loss of sensation and voluntary motion in the lower part of the body, in consequence of destructive disease or injury of a portion, including the whole thickness, of the spinal cord. Such lesions destroy the communication between the brain and all parts of the spinal cord below the seat of injury, and consequently cut off from their connection with the brain the various organs supplied with nerves issuing from those parts of the cord.

It is probable that the conduction of impressions along the cord is effected (at least, for the most part) through the grey substance, *i.e.*, through the nerve-corpuscles and filaments connecting them. But all parts of the cord are not alike able to conduct all impressions; and as there are separate nerve-fibres for motor and for sensory impressions, so in the cord, separate and determinate parts serve to conduct always the same kind of impression.

Experiments (chiefly by Brown-Séquard), point to the following conclusions regarding the conduction of sensory and motor impressions through the spinal cord.

It is important to bear in mind that the *grey* matter of the cord, though it conducts impressions giving rise to sensation, appears not to be sensitive when it is directly stimulated. The explanation probably is, that it possesses no apparatus such as exists at the peripheral terminations of sensory nerves, for the reception of sensory impressions.

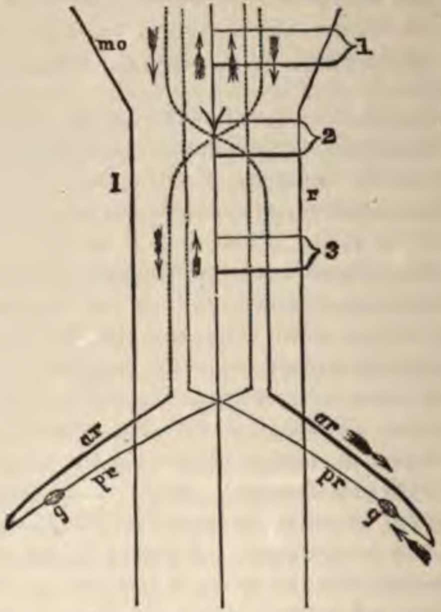


FIG. 320.—Diagram of the decussation of the conductors for voluntary movements, and those for sensation: *a*, *r*, anterior roots and their continuations in the spinal cord, and decussation at the lower part of the medulla oblongata, *m o; p r*, the posterior roots and their continuation and decussation in the spinal cord; *g g*, the ganglions of the roots. The arrows indicate the direction of the nervous action; *r*, the right side; *l*, the left side. 1, 2, 3, indicate places of alteration in a lateral half of the spino-cerebral axis, to show the influence on the two kinds of conduct resulting from section of the cord at any one of these three places. (After Brown-Séquard.)

a. Sensory impressions, conveyed to the spinal cord by root-fibres of the posterior nerves are not conducted to the brain only by the posterior columns of the cord, but pass through them in great part into the central grey substance, by which they are transmitted to the brain (*p r*, Fig. 320).

b. The impressions thus conveyed to the grey substance do not pass up to the brain to more than a slight degree, along that half of the cord corresponding to the side from which they have been received, but cross over to the other side almost immediately after entering the cord, and along it are transmitted to the brain. There is thus, in the cord itself, an almost complete decussation of sensory impressions brought to it; so that division or disease of one posterior half of the cord (3, Fig. 320) is followed by loss of sensation, not in parts on the corresponding, but in those of the opposite side of the body. From the same fact it happens that a longitudinal antero-posterior section of the cord, along its whole length, most completely abolishes sensibility on both sides of the body.

c. The various sensations of touch, pain, temperature, and muscular contraction, are probably conducted along separate and distinct sets of fibres. All, however, with the exception of the last named, undergo decussation in the spinal cord.

d. The posterior columns of the cord appear to have a great share in reflex movements.

e. Impulses of the will, leading to voluntary contractions of muscles, appear to be transmitted principally along the antero-lateral columns; but if a transverse section of this part be made (the grey matter being intact) although at first no voluntary movements of the part below occur, this paralysis is only temporary, indicating that the grey matter may take on the conduction of these impulses.

f. Decussation of motor impulses occurs, not in the spinal cord, as is the case with sensory impressions, but at the anterior part of the medulla oblongata (Fig. 321). Hence, motor impulses, having made their decussation, first enter the cord by the lateral tracts and adjoining grey matter, and then pass to the anterior columns and to the grey matter associated with them. Accordingly, division of the anterior pyramids, at the point of decussation (2, Fig. 320), is followed by paralysis of motion in all parts below; while division of the olivary bodies which constitute the true continuations of the anterior columns of the cord, appears to produce very little paralysis. Disease or division of any part of the cerebro-spinal axis above the seat of decussation (1, Fig. 320) is followed, as well-known, by impaired or lost power of motion on the opposite side of the body; while a like injury inflicted below this part (3, Fig. 320), induces similar paralysis on the corresponding side.

When one half of the spinal cord is cut through, complete anæsthesia of the other side of the body below the point of section results, but there is often greatly increased sensibility (hyperæsthesia) on the same side; so much so that the least touch appears to be agonizing. This condition may persist for several days. Similar effects may, in man, be the result of injury. Thus, in a patient who had sustained a severe lesion of the spinal cord in the cervical region, causing extensive paralysis and loss of sensation in the lower half of the body, there were two circumscribed areas, one on each arm, symmetrically placed, in which the gentlest touch caused extreme pain.

In addition to the transmission of ordinary sensory and motor impulses, the spinal cord is the medium of conduction also of impulses to and from the *vaso-motor centre* in the medulla oblongata, and probably also contains special vaso-motor centres.

2. **Transference.**—Examples of the transference of impressions in the cord have been given (p. 84, Vol. II.); and that the transference takes place in the cord, and not in the brain, is nearly proved by the frequent cases of pain felt in the knee and not in the hip, in diseases of the hip; of pain felt in the urethra or glans penis, and not in the bladder, in calculus; for, if both the primary and the secondary or transferred impression were in the brain, both should be felt.

3. **Reflection.**—In man the spinal cord is so much under the control of the higher nerve-centres, that its own individual functions in relation to reflex action are apt to be overlooked; so that the result of injury, by which the cord is cut off completely from the influence of the encephalon, is apt to lessen rather than increase our estimate of its importance and individual endowments. Thus, when the human spinal cord is divided, the lower extremities fall into any position that their weight and the resistance of surrounding objects combine to give them; if the body is irritated, they do not move toward the irritation; and if they are touched, the consequent reflex movements are disorderly and purposeless; all power of voluntary movement is absolutely abolished. In other mammals, *e.g.*, rabbit or dog, after recovery from the shock of the operation, which takes some time, reflex actions in the parts below will occur after the spinal cord has been divided, a very feeble irritation being followed by extensive and co-ordinate movements. In the case of the frog, however, and many other cold-blooded animals, in which experimental and other injuries of the nerve-tissues are better borne, and in which the lower nerve-centres are less subordinate in their action to the higher, the reflex functions of the cord are still more clearly shown. When, for example, a frog's head is cut off, the limbs remain in or assume a natural position; they resume it when disturbed; and when the abdomen or back is irritated, the feet are moved with the manifest purpose of pushing away the irritation. The main difference in the cold-blooded animals being that the reflex movements are more definite, complicated, and effective, although less energetic than in the case of mammals. It is as if the mind of the animal were still engaged in the acts; and yet all analogy would lead us to the belief that the spinal cord of the frog has no different endowment, in *kind*, from those which belong to the cord of the higher vertebrata: the difference is only in *degree*. And if this be granted, it may be assumed that, in man and the higher animals, many actions are performed as reflex movements occurring through and by means of the spinal cord, although the latter cannot by itself initiate or even direct them independently.

Co-ordinate Movement not a proof of Consciousness.—The evident adaptation and purpose in the movements of the cold-blooded animals, have led some to think that they must be conscious and capable of will without their brains. But purposive movements are no proof of consciousness or will in the creature manifesting them. The movements of the limbs of headless frogs are not more purposive than the movements of our own respiratory muscles are; in which we know that neither will nor consciousness is at all times concerned. It may not, indeed, be assumed that the acts of standing, leaping, and other movements, which decapitated cold-blooded animals can perform, are also always, in the entire and healthy state, performed involuntarily, and under the sole influence of the cord; but it is probable that such acts may be, and commonly are, so performed, the higher nerve-centres of the animal having only the same kind of influence in modifying and directing them, that those of man have in modifying and directing the movements of the respiratory muscles.

Inhibition of Reflex Actions.—The fact that such movements as are produced by irritating the skin of the lower extremities in the human subject, after division or disorganization of a part of the spinal cord, do not follow the same irritation when the mind is active and connected with the cord through the brain, is, probably, due to the mind ordinarily perceiving the irritation and instantly controlling the muscles of the irritated and other parts; for, even when the cord is perfect, such involuntary movements will often follow irritation, if it be applied when the mind is wholly occupied. When, for example, one is anxiously thinking, even slight stimuli will produce involuntary and reflex movements. So, also, during sleep, such reflex movements may be observed, when the skin is touched or tickled; for example, when one touches with the finger the palm of the hand of a sleeping child, the finger is grasped—the impression on the skin of the palm producing a reflex movement of the muscles which close the hand. But when the child is awake, no such effect is produced by a similar touch.

Further, many reflex actions are capable of being more or less controlled or even altogether prevented by the will: thus an *inhibitory* action may be exercised by the brain over reflex functions of the cord and the other nerve centres. The following may be quoted as familiar examples of this inhibitory action:—

To prevent the reflex action of crying out when in pain, it is often sufficient firmly to clench the teeth or to grasp some object and hold it tight. When the feet are tickled we can, by an effort of will, prevent the reflex action of jerking them up. So, too, the involuntary closing of the eyes and starting, when a blow is aimed at the head, can be similarly restrained.

Darwin has mentioned an interesting example of the way in which, on the other hand, such an instinctive reflex act may override the strongest effort of the will. He placed his face close against the glass of the cobra's cage in the Reptile House at the Zoological Gardens, and though, of course, thoroughly convinced of his perfect security, could not by any effort of the will prevent himself from starting back when the snake struck with fury at the glass.

It has been found by experiment that in a frog the optic lobes and optic thalami have a distinct action in inhibiting or delaying reflex action, and also that more generally any afferent stimulus, if sufficiently strong, may *inhibit* or *modify* any reflex action even in the absence of these centres.

On the whole, therefore, it may, from these and like facts, be concluded that reflex acts, performed under the influence of the reflecting power of the spinal cord, are essentially independent of the brain and may be performed perfectly when the brain is separated from the cord: that these include a much larger number of the natural and purposive movements of the lower animals than of the warm-blooded animals and man: and that over nearly all of them the mind may exercise, through the higher nerve centres, some control; *determining, directing, hindering,* or *modifying* them, either by direct action, or by its power over associated muscles.

To these instances of spinal reflex action, some add yet many more, including nearly all the acts which seem to be performed unconsciously, such as those of walking, running, writing, and the like: for these are really involuntary acts. It is true that at their first performances they are voluntary, that they require education for their perfection, and are at all times so constantly performed in obedience to a mandate of the will, that it is difficult to believe in their essentially involuntary nature. But the will really has only a *controlling* power over their performance; it can hasten or stay them, but it has little or nothing to do with the actual carrying out of the effect. And this is proved by the circumstance that these acts can be performed with complete mental abstraction: and, more than this, that the endeavor to carry them out entirely by the exercise of the will is not only not beneficial, but positively interferes with their harmonious and perfect performance. Any one may convince himself of this fact by trying to take each step as a voluntary act in walking down stairs, or to form each letter or word in writing by a distinct exercise of the will.

These actions, however, will be again referred to, when treating of their possible connection with the functions of the so-called *sensory ganglia*, p. 115 *et seq.*, Vol. II.

Morbid reflex actions.—The relation of the reflex action to the strength of the stimulus is the same as was shown generally in the action of ganglia, a slight stimulus producing a slight (p. 87, Vol. II.) movement, and a greater, a greater movement, and so on; but in instances in which we must assume that the cord is *morbidly more irritable, i.e.*, apt to issue more nervous force than is proportionate to the stimulus applied to it, a slight impression on a sensory nerve produces extensive reflex movements. This appears to be the condition in tetanus, in which a slight touch on the skin may throw the whole body into convulsion. A similar state is induced by the introduction of strychnia and, in frogs, of opium into the blood; and numerous experiments on frogs thus made tetanic, have shown that the tetanus is wholly unconnected with the brain, and depends on the state induced in the spinal cord.

Special Centres in Spinal Cord.—It may seem to have been implied that the spinal cord, as a single nerve-centre, reflects alike from all parts all the impressions conducted to it. But it is more probable that it should be regarded as a collection of nervous centres united in a continuous column. This is made probable by the fact that segments of the cord may act as distinct nerve-centres, and excite motions in the parts supplied with nerves given off from them; as well as by the analogy of certain cases in which the muscular movements of single organs are under the control of certain circumscribed portions of the cord. Thus,—for the governance of the sphincter-muscles concerned in guarding the orifices respectively of the rectum and urinary bladder there are special nerve-centres in the lower part of the spinal cord (*ano-spinal* and *vesico-spinal* centres); while the actions of these are temporarily *inhibited* by stimuli which lead to defæcation and micturition. So, also, there are centres directly concerned in erection of the penis and in the emission of semen (*genito-urinary*). The *emission of semen* is a reflex act: the irritation of the glans penis conducted to the spinal cord, and thence reflected, excites the successive and co-ordinate contractions of the muscular fibres of the vasa deferentia and vesiculæ seminales, and of the accelerator urinæ and other muscles of the urethra; and a forcible expulsion of semen takes place, over which the mind has little or no control, and which, in cases of paraplegia, may be unfelt. *The erection of the penis*, also, as already explained (p. 169, Vol. I.), appears to be in part the result of a reflex contraction of the muscles by which the veins returning the blood from the penis are compressed. The involuntary *action of the uterus in expelling its contents during parturition*, is also of a purely reflex kind, dependent in part upon the spinal cord, though in part also upon the sympathetic system: its independence of the brain being proved by cases of delivery in paraplegic women, and also by the fact that delivery can take place whilst the patient is under the influence of chloroform. But all these spinal nerve-centres are intimately connected, both structurally and physiologically, one with another, as well as with those higher encephalic centres, without whose guiding influence their actions may become disorderly and purposeless, or altogether abrogated.

Centre for Movements of Lymphatic Hearts of Frog.—Volkmann has shown that the rhythmical movements of the anterior pair of lymphatic hearts in the frog depend upon nervous influence derived from the portion of spinal cord corresponding to the third vertebra, and those of the posterior pair on influence supplied by the portion of cord opposite the eighth vertebra. The movements of the heart continue, though the whole of the cord, except the above portions, be destroyed; but on the instant of destroying either of these portions, though all the rest of the cord be untouched, the movements of the corresponding hearts cease. What appears to be thus proved in regard to two portions of the cord, may be inferred to prevail in other portions also; and the inference is reconcilable with most of the facts known concerning the physiology and comparative anatomy of the cord.

Tone of Muscles.—The influence of the spinal cord on the sphincter ani (centre for *defæcation*) has been already mentioned (see above). It maintains this muscle in permanent contraction, so that, except in the act of defæcation, the orifice of the anus is always closed. This influence of the cord resembles its common reflex action in being involuntary, although the will can act on the muscle to make it contract more, or may inhibit the action of the ano-spinal centre so as to permit its dilatation. The condition of the sphincter ani, however, is not altogether exceptional. It is the same in kind, though it exceeds in degree that condition of muscles which has been called *tone*, or passive contraction; a state in which they always when not active appear to be during health, and in which, though called inactive, they are in slight contraction, and certainly are not relaxed, as they are long after death, or when the spinal cord is destroyed. This tone of all the muscles of the trunk and limbs depends on the spinal cord, as the contraction of the sphincter ani does. If an animal be killed by injury or removal of the brain the tone of the muscles may be felt and the limbs feel firm as during sleep; but if the spinal cord be destroyed, the sphincter ani relaxes, and all the muscles feel loose, and flabby, and atonic, and remain so till *rigor mortis* commences. This kind of tone must be distinguished from that mere firmness and tension which it is customary to ascribe, under the name of *tone*, to all tissues that feel robust and not flabby, as well as to muscles. The tone peculiar to muscles has in it a degree of vital contraction: that of other tissues is only due to their being well nourished, and therefore compact and tense.

All the foregoing examples illustrate the fact that the spinal cord is a collection of reflex centres, upon which the higher centres act by sending down impulses to set in motion, to modify or to control them; the movements or other phenomena of reflection being as it were the function of the ganglion cells to set in action, after an afferent impression has been conveyed to them by the posterior nerve-trunks in connection with them. The extent of the resulting movement depends upon the strength of the stimulus, the position at which it was applied as well as upon the condition of the nerve cells; the connection between the cells being so intimate that a series of co-ordinated movements may result from a single stimulation, first of all affecting one cell. Whether the cells possess as well the power of originating impulses (automatism) is doubtful, but this is possible in the case of *vaso-motor centres* which are situated in the cord (p. 154, Vol. I.), and of *sweating centres* which must be closely related to them, and possibly in the case of the centres for maintaining the *tone of muscles*.

THE MEDULLA OBLONGATA.

The medulla oblongata (Figs. 321, 322), is a column of grey and white nervous substance formed by the prolongation upward of the spinal cord and connecting it with the brain.

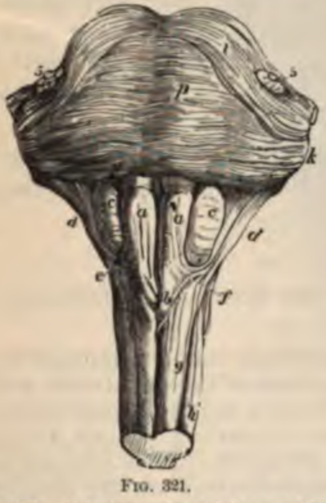


FIG. 321.

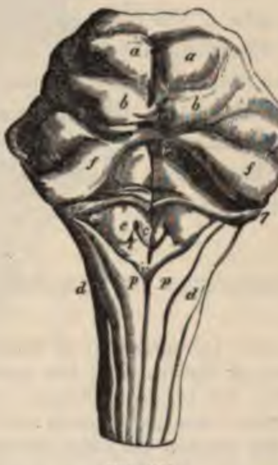


FIG. 322.

FIG. 321.—Anterior surface of the pons Varolii, and medulla oblongata. *a*, *a*, anterior pyramids; *b*, their decussation; *c*, *c*, olivary bodies; *d*, *d*, restiform bodies; *e*, arciform fibres; *f*, fibres described by Solly as passing from the anterior column of the cord to the cerebellum; *g*, anterior column of the spinal cord; *h*, lateral column; *p*, pons Varolii; *i*, its upper fibres; 5, 5, roots of the fifth pair of nerves.

FIG. 322.—Posterior surface of the pons Varolii, corpora quadrigemina, and medulla oblongata. The peduncles of the cerebellum are cut short at the side. *a*, *a*, the upper pair of corpora quadrigemina; *b*, *b*, the lower; *f*, *f*, superior peduncles of the cerebellum; *c*, eminence connected with the nucleus of the hypoglossal nerve; *e*, that of the glosso-pharyngeal nerve; *i*, that of the vagus nerve; *d*, *d*, restiform bodies; *p*, *p*, posterior pyramids; *v*, *v*, groove in the middle of the fourth ventricle, ending below in the calamus scriptorius; 7, 7, roots of the auditory nerves.

Structure.—The grey substance which it contains is situated in the interior, and variously divided into masses and laminæ by the white or fibrous substance which is arranged partly in external columns, and partly in fasciculi traversing the central grey matter. The medulla oblongata is larger than any part of the spinal cord. Its columns are pyriform, enlarging as they proceed toward the brain, and are continuous with those of the spinal cord. Each half of the medulla, therefore, may be divided into three columns or tracts of fibres, continuous with the three tracts of which each half of the spinal cord is made up. The columns are more prominent than those of the spinal cord, and separated from each other by deeper grooves. The *anterior*, continuous with the anterior columns of the cord, are called the anterior *pyramids;* the *posterior*, continuous with the posterior columns of the cord, and comprising the funiculus cuneatus, and the funiculus of Rolando (Fig. 323, *f.c.*, *f.R.*), are called the *restiform* bodies. On the outer side of the anterior pyramids of each side, near its upper part, is a small oval mass containing grey matter, and named the *olivary body;* and at the posterior part of the restiform column, immediately on each side of the posterior median groove, continuous with the posterior median column of the cord, a small tract is marked off by a slight groove from the remainder of the restiform body, and called the *posterior pyramid* or *fasciculus gracilis.* The restiform columns, instead of remaining parallel with each other throughout the whole length of the medulla oblongata, diverge near its upper part, and by thus diverging, lay open, so to speak, a space called the fourth ventricle, the floor of which is formed by the grey matter of the interior of the medulla, by this divergence exposed.

On separating the anterior pyramids, and looking into the groove between them, some decussating fibres of the lateral columns of the cord can be plainly seen.

DISTRIBUTION OF THE FIBRES OF THE MEDULLA OBLONGATA.

The *anterior pyramid* of each side, although mainly composed of continuations of the fibres of the anterior columns of the spinal cord, receives fibres from the lateral columns, both of its own and the opposite side; the latter fibres forming almost entirely the decussating strands which are seen in the groove between the anterior pyramids. Thus composed, the anterior pyramidal fibres proceeding onward to the brain are distributed in the following manner:—

1. The greater part pass on through the Pons to the Cerebrum. A portion of the fibres, however, running apart from the others, joins some fibres from the olivary body, and unites with them to form what is called the *olivary fasciculus* or *fillet.* 2. A small tract of fibres proceeds to the cerebellum.

The *lateral column* of the cord on each side of the medulla, in proceeding upward, divides into three parts, outer, inner, and middle, which are thus disposed of:—1. The *outer* fibres (direct cerebellar tract) go with the restiform tract to the cerebellum. 2. The *middle* (crossed pyramidal tract) decussate across the middle line with their fellows, and form a part of the anterior pyramid of the opposite side. 3. The *inner* pass on to the cerebrum, at first superficially but afterward beneath the olivary body and the arcuate fibres, and then proceed along the floor of the fourth ventricle, on each side, under the name of the *fasciculus teres.*

The posterior column of the cord is represented in the medulla by the *posterior pyramid*, or fasciculus gracilis, which is a continuation of the posterior median column, and by the *restiform body*, comprising the funiculus cuneatus and the funiculus of Rolando. The fasciculus gracilis (Fig. 323, *f.g*), diverges above as the broader clava to form, one on either side, the lower lateral boundary of the fourth ventricle, then tapers off, and becomes no longer traceable. The funiculus cuneatus, or the rest of the posterior column of the cord, is continued up in the medulla as such (Fig. 323, *f.c*); but soon, in addition, between this and the continuation of the posterior nerve roots, appears another tract called the funiculus of Rolando (Fig. 323, *f.R*). High up, the funiculus cuneatus is covered by a set of fibres (arcuate fibres), which issue from the anterior median fissure, turn upward over the anterior pyramids to pass directly into the corresponding hemisphere of the cerebellum, being joined by the fibres of the direct cerebellar tract; the funiculus of Rolando, and the funiculus cuneatus, although appearing to join them, do not actually do so, except to a partial extent.

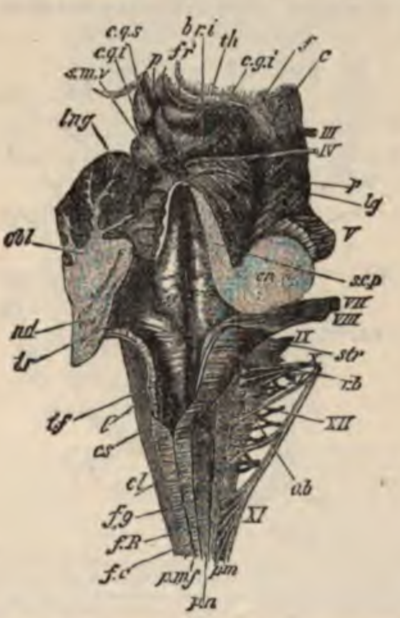


FIG. 323.—Posterior view of the medulla, fourth ventricle, and mesencephalon (natural size). *p. n*, line of the posterior roots of the spinal nerves; *p.m.f.*, posterior median fissure; *f.g.*, funiculus gracilis; *cl.*, its clavis; *f.c.*, funiculus cuneatus; *f.R.*, funiculus of Rolando; *r.b.*, restiform body; *c.s.*, calamus scriptorius; *l.*, section of ligula or tænia; part of choroid plexus is seen beneath it; *l.r.*, lateral recess of the ventricle; *str.*, striæ acusticæ; *i.f.*, inferior fossa; *s.f.*, posterior fossa; between it and the median sulcus is the fasciculus teres; *cbl.*, cut surface of the cerebellar hemisphere; *n.d.*, central or grey matter; *s.m.v.*, superior medullary velum; *lng.*, ligula; *s.c.p.*, superior cerebellar peduncle cut longitudinally; *cr.*, combined section of the three cerebellar peduncles; *c.q.s.*, *c.q.i.*, corpora quadrigemina (superior and inferior); *fr.*, frænulum; *f.*, fibres of the fillet seen on the surface of the tegmentum; *c.*, crusti; *l.g.*, lateral groove; *c.g.i.*, corpus geniculum internus; *th.*, posterior part of thalamus; *p.*, pineal body. The roman numbers indicate the corresponding cranial nerves. (E. A. Schäfer.)

Grey matter of the medulla.—To a considerable extent the grey matter of the medulla is a continuation of that in the spinal cord, but the arrangement is somewhat different.

The displacement of the anterior cornu takes place because of the decussation of a large part of the fibres of the lateral columns in the anterior pyramids passing through the grey matter of the anterior cornu, so that the caput cornu is cut off from the rest of the grey matter, and is, moreover, pushed backward by the olivary body, to be mentioned below. It lies in the lateral portion of the medulla, and exists for a time as the *nucleus lateralis* (Fig. 324, *n.l*); it consists of a reticulum of grey matter, containing ganglion cells intersected by white nerve fibres. The base of the anterior cornu is pushed more from the anterior surface, and when

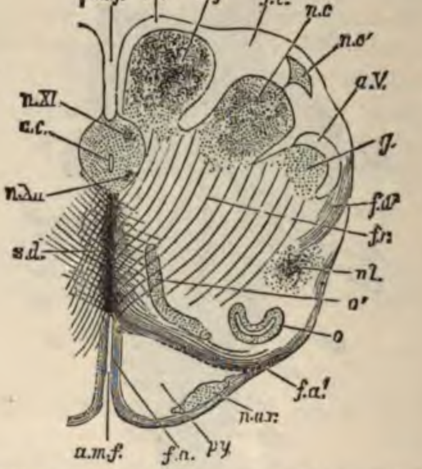


FIG. 324.—Section of the medulla oblongata in the region of the superior pyramidal decussation. *a.m.f.*, anterior median fissure; *f.a.*, superficial arciform fibres emerging from the fissure; *py.*, pyramid; *n.a.r.*, nuclei of arciform fibres; *f.a*¹, deep arciform becoming superficial; *o.*, lower end of olivary nucleus; *n.l.*, nucleus lateralis; *f.r.*, formatio reticularis; *f.a*², arciform fibres proceeding from the formatio reticularis; *g.*, substantia gelatinosa of Rolando; *a.V.*, ascending root of fifth nerve; *n.c.*, nucleus cuneatus; *n.c′.*, external cuneate nucleus; *n.g.*, nucleus gracilis; *f.g.*, nucleus gracilis; *p.m.f.*, posterior median fissure; *c.c.*, central canal surrounded by grey matter, in which are *n.XI.*, nucleus of the spinal accessory, and *n.XII.*, nucleus of the hypoglossal; *s.d.*, superior pyramidal decussation. (Schwalbe.) (Modified from Quain.)

the central canal opens out into the fourth ventricle, forms a collection of ganglion cells, producing the eminence of the fasciculus teres; from certain large cells in it arise the hypoglossal nerve (Fig. 325, *XII.*), which passes through the medulla, and appears between the olivary body and the anterior pyramids.

In the funiculus teres, nearer to the middle line as well as to the surface, is a collection of nerve cells called the nucleus of that funiculus (Fig. 325, *n.t*). The grey matter of the posterior cornu is displaced somewhat by bands of fibres passing through it. The caput cornu appears at the surface as the funiculus of Rolando, whilst the cervix cornu is broken up into a reticulated structure which is displaced laterally, similar in structure to the nucleus lateralis. From the increase of the base of the posterior cornu, the nuclei of the funiculus gracilis and funiculus cuneatus are derived (Fig. 324, *n.g*, *n.c*), and outside of the latter is an accessory nucleus formed (Fig. 324, *n.c'*). Internally to these latter, and also derived from the cells of the base of the posterior cornu and appearing in the floor of the fourth ventricle, when the central canal opens are the nuclei of the spinal accessory, vagus, and glosso-pharyngeal nerves. In the upper part of the medulla also, to the outside of these three nuclei, is found the principal auditory nucleus. All the above nuclei appear to be derived from a continuation of the grey matter of the spinal cord, but a fresh collection of grey matter not represented is interpolated between the anterior pyramids and the lateral column, contained within the olivary prominence, the wavy line of which (corpus dentatum) is doubled upon itself at an angle with the extremities directed upward and inward (Fig. 325, *o*). There may also be a smaller collection of grey matter on the outer and inner side of the olivary nucleus known as accessory olivary nuclei.

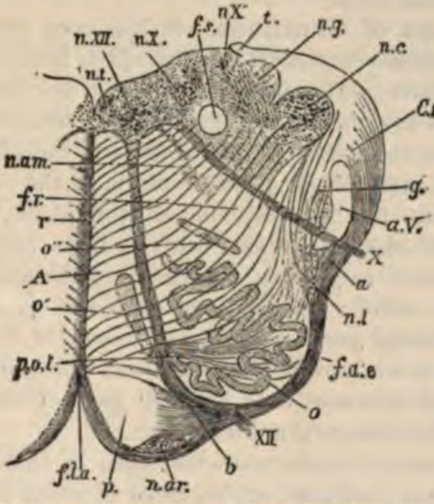


FIG. 325.—Section of the medulla oblongata at about the middle of the olivary body. *f.l.a.*, anterior median fissure; *n.a.r.*, nucleus arciformis; *p*, pyramid; *XII.*, bundle of hypoglossal nerve emerging from the surface; at *b*, it is seen coursing between the pyramid and the olivary nucleus, *o.*; *f.a.e.*, external arciform fibres; *n.l.*, nucleus lateralis; *a*, arciform fibres passing toward restiform body, partly through the substantia gelatinosa, *g.*, partly superficial to the ascending root of the fifth nerve, *a.V.*; *X*, bundle of vagus root emerging; *f.r.*, formatio reticularis; *c.r.*, corpus restiforme, beginning to be formed, chiefly by arciform fibres, superficial and deep; *n.c.*, nucleus cuneatus; *n.g.*, nucleus gracilis; *t.*, attachment of the ligula; *f.s.*, funiculus solitarius; *n.X.*, *nX'.*, two parts of the vagus nucleus; *n.XII.*, hypoglossal nucleus; *n.t.*, nucleus of the funiculus teres: *n.am.*, nucleus ambiguous; *r.*, raphe; *A.*, continuation of the anterior column of cord; *o'*, *o''*., accessory olivary nucleus; *p.o.*, pedunculus olivæ. (Schwalbe.) (Modified from Quain.)

FUNCTIONS OF THE MEDULLA OBLONGATA.

The functions of the medulla oblongata, like those of the spinal cord, may be considered under the heads of: 1. Conduction; 2. Transference and Reflection; and, in addition, 3. Automatism.

1. In *conducting* impressions the medulla oblongata has a wider extent of function than any other part of the nervous system, since it is

obvious that all impressions passing to and fro between the brain and the spinal cord and all nerves arising below the pons, must be transmitted through it.

2. As a nerve-centre by which impressions are *transferred* or *reflected*, the medulla oblongata also resembles the spinal cord; the only difference between them consisting of the fact that many of the reflex actions performed by the former are much more important to life than any performed by the spinal cord.

Demonstration of Functions.—It has been proved by repeated experiments on the lower animals that the entire brain may be gradually cut away in successive portions, and yet life may continue for a considerable time, and the respiratory movements be uninterrupted. Life may also continue when the spinal cord is cut away in successive portions from below upward as high as the point of origin of the phrenic nerve. In Amphibia, the brain has been all removed from above, and the cord, as far as the medulla oblongata, from below; and so long as the medulla oblongata was intact, respiration and life were maintained. But if, in any animal, the medulla oblongata is wounded, particularly if it is wounded in its central part, opposite the origin of the pneumogastric nerves, the respiratory movements cease, and the animal dies asphyxiated. And this effect ensues even when all parts of the nervous system, except the medulla oblongata, are left intact.

Injury and disease in men prove the same as these experiments on animals. Numerous instances are recorded in which injury to the medulla oblongata has produced instantaneous death; and, indeed, it is through injury of it, or of the part of the cord connecting it with the origin of the phrenic nerve, that death is commonly produced in fractures and diseases with sudden displacement of the upper cervical vertebræ.

SPECIAL CENTRES.

(1.) *Respiratory.*—The centre whence the nervous force for the production of combined respiratory movements appears to issue is in the interior of that part of the medulla oblongata from which the pneumogastric nerves or Vagi arise. The vagi themselves, indeed, are not essential to the respiratory movements; for both may be divided without more immediate effect than a retardation of these movements. But in this part of the medulla oblongata is the nerve-centre whence the impulses producing the respiratory movements issue, and through which impulses conveyed from distant parts are reflected.

The wide extent of connection which belongs to the medulla oblongata as the centre of the respiratory movements, is shown by the fact that impressions by mechanical and other ordinary stimuli, made on many parts of the external or internal surface of the body, may modify, *i.e.*, increase or diminish the rapidity of respiratory movements. Thus involuntary respirations are induced by the sudden contact of cold with any part of the skin, as in dashing cold water on the face. Irritation of the mucous membrane of the nose produces sneezing. Irritation in the pharynx, œsophagus, stomach, or intestines, excites the concurrence of the respiratory movements to produce vomiting. Violent irritation in the rectum, bladder, or uterus, gives rise to a concurrent action of the respiratory muscles, so as to effect the expulsion of the fæces, urine, or fœtus.

(2.) *Centre for Deglutition.*—The medulla oblongata appears to be the centre whence are derived the motor impulses enabling the muscles of the palate, pharynx, and œsophagus to produce the successive co-ordinate and adapted movements necessary to the act of *deglutition* (p. 239, Vol. I.). This is proved by the persistence of swallowing in some of the lower animals after destruction of the cerebral hemispheres and cerebellum; its existence in anencephalous monsters; the power of swallowing possessed by the marsupial embryo before the brain is developed; and by the complete arrest of the power of swallowing when the medulla oblongata is injured in experiments. (3) A centre by which the movements of *mastication* are regulated (p. 226, Vol. I.). (4) Through the medulla oblongata, chiefly, are reflected the impressions which excite the *secretion of saliva* (p. 232, Vol. I.). (5) *Cardio-inhibitory* centre for the regulation of the action of the heart, through the pneumogastrics and probably also, the accelerating fibres of the sympathetic (p. 127, Vol. I.). (6) The chief *vaso-motor* centre. From this centre arise fibres which, passing down the spinal cord, issue with the anterior roots of the spinal nerves, and enter the ganglia and branches of the sympathetic system, by which they are conducted to the blood-vessels (p. 154, Vol. I.). (7) *Cilio-spinal* centre for the regulation of the iris, and other plain-fibred muscles of the eye. (8 and 9) Centres or ganglia of the special senses of *hearing* and *taste.* (10) The centre for *speech, i.e.,* the centre by which the various muscular movements concerned in speech are co-ordinated or harmonized. (11) Centre by which the many muscles concerned in *vomiting* are harmonized. (12) The so-called *diabetic* centre, or, in other words, the grey matter in the medulla oblongata which, being irritated, causes glycosuria (p. 283, Vol. I.), is probably the vaso-motor centre; and this peculiar result of its stimulation is merely due to vaso-motor changes in the liver.

Though respiration and life continue while the medulla oblongata is perfect and in connection with the respiratory nerves, yet, when all the brain above it is removed, there is no more appearance of sensation, or will, or of any mental act in the animal, the subject of the experiment, than there is when only the spinal cord is left. The movements are all involuntary and unfelt; and the medulla oblongata has, therefore, no claim to be considered as an organ of the mind, or as the seat of sensation or voluntary power. These are connected with parts to be afterward described.

PONS VAROLII.

Structure.—The meso-cephalon, or pons Varolii (VI, Fig. 326), is composed principally of transverse fibres connecting the two hemispheres of the cerebellum, and forming its principal transverse commissure. But it includes, interlacing with these, numerous longitudinal fibres which connect the medulla oblongata with the cerebrum, and transverse fibres which connect it with the cerebellum. Among the fasciculi of nerve-fibres by which these several parts are connected, the pons also contains abundant grey or vesicular substance, which appears irregularly placed among the fibres, and fills up all the interstices.

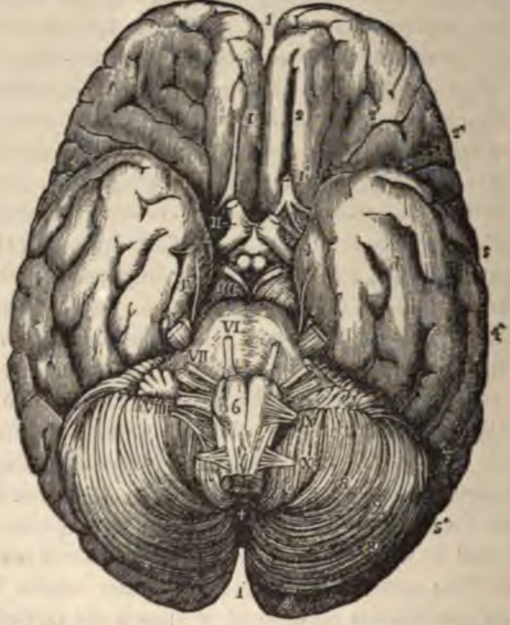


FIG. 326.—Base of the brain. 1, superior longitudinal fissure; 2, 2′, 2″, anterior cerebral lobe; 3, fissure of Sylvius, between anterior and 4,4′,4″, middle cerebral lobe; 5, 5′, posterior lobe; 6, medulla oblongata; the figure is in the right anterior pyramid; 7,8,9,10, the cerebellum; +, the inferior vermiform process. The figures from I. to IX. are placed against the corresponding cerebral nerves; III. is placed on the right crus cerebri. VI. and VII. on the pons Varolii; X. the first cervical or sub-occipital nerve. (Allen Thomson). ½.

Functions.—The anatomical distribution of the fibres, both transverse and longitudinal, of which the pons is composed, is sufficient evidence of its functions as a conductor of impressions from one part of the cerebro-spinal axis to another. Concerning its functions as a nerve-centre, little or nothing is certainly known.

CRURA CEREBRI.

Structure.—The *crura cerebri* (III, Fig. 326), are principally formed of nerve-fibres, of which the inferior or more superficial (crusta) are continuous with those of the anterior pyramidal tracts of the medulla oblongata, and the superior or deeper fibres (tegmentum) with the lateral and posterior pyramidal tracts, and with the olivary fasciculus. Besides these fibres from the medulla oblongata, are others from the cerebellum; and some of the latter as well as a part of the fibres derived from the lateral tract of the medulla oblongata, decussate across the middle line.

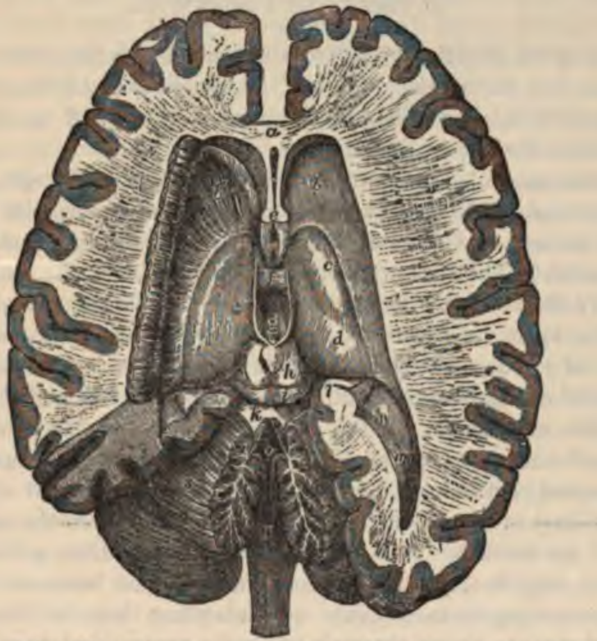


Fig. 327.—Dissection of brain, from above, exposing the lateral fourth and fifth ventricles with the surrounding parts. ½.—*a*, anterior part, or *genu* of corpus callosum; *b*, corpus striatum; *b′*, the corpus striatum of left side, dissected so as to expose its grey substance; *c*, points by a line to the tænia semicircularis; *d*, optic thalamus; *e*, anterior pillars of fornix divided; below they are seen descending in front of the third ventricle, and between them is seen part of the anterior commissure; in front of the letter *e* is seen the slit-like fifth ventricle, between the two laminæ of the septum lucidum; *f*, soft or middle commissure; *g*, is placed in the posterior part of the third ventricle; immediately behind the latter are the posterior commissure (just visible) and the pineal gland, the two crura of which extend forward along the inner and upper margins of the optic thalami; *h* and *i*, the corpora quadrigemina; *k*, superior crus of cerebellum; close to *k* is the valve of Vieussens, which has been divided so as to expose the fourth ventricle; *l*, hippocampus major and corpus fimbriatum, or tænia hippocampi; *m*, hippocampus minor; *n*, eminentia collateralis; *o*, fourth ventricle; *p*, posterior surface of medulla oblongata; *r*, section of cerebellum; *s*, upper part of left hemisphere of cerebellum exposed by the removal of part of the posterior cerebral lobe. (Hirschfeld and Leveillé.)

Each crus cerebri contains among its fibres a mass of grey substance, the *locus niger*.

Functions.—With regard to their functions, the crura cerebri may be regarded as, principally, conducting organs: the *crusta* conducting motor and the *tegmentum* sensory impressions. As nerve-centres they are probably connected with the functions of the third cerebral nerve, which arises from the *locus niger*, and through which are directed the chief of the numerous and complicated movements of the eyeball. The crura cerebri are also in all probability connected with the co-ordination of other movements besides those of the eye, as either rotatory (p. 119, Vol. II.) or disorderly movements result after section of either of them.

CORPORA QUADRIGEMINA.

The corpora quadrigemina (from which, in function, the *corpora geniculata* are not distinguishable), are the homologues of the optic lobes in Birds, Amphibia, and Fishes, and may be regarded as the principal nerve-centres for the sense of sight.

Functions.—(1) The experiments of Flourens, Longet, and Hertwig, show that removal of the corpora quadrigemina wholly destroys the power of seeing; and diseases in which they are disorganized are usually accompanied by blindness. Atrophy of them is also often a consequence of atrophy of the eyes. Destruction of one of the corpora quadrigemina (or of one optic lobe in birds), produces blindness of the opposite eye. This loss of sight is the only apparent injury of sensibility sustained by the removal of the corpora quadrigemina. The (2) removal of one of them affects the movements of the body, so that animals rotate, as after division of the crus cerebri, only more slowly: but this may be due to giddiness and partial loss of sight. (3) The more evident and direct influence is that produced on the iris. It contracts when the corpora quadrigemina are irritated: it is always dilated when they are removed: so that they may be regarded, in some measure at least, as the nervous centres governing its movements, and adapting them to the impressions derived from the retina through the optic nerves and tracts. (4) The centre for the co-ordination of the movements of the eyes is also contained in them. This centre is closely associated with that for contraction of the pupil, and so it follows that contraction or dilatation follows upon certain definite ocular movements.

CORPORA STRIATA AND OPTIC THALAMI.

Structure.—(1.) The corpora striata are situated in front of the optic thalami, partly within and partly without the lateral ventricle. Each corpus striatum consists of two parts.

(*a.*) Intraventricular portion (*caudate nucleus*) is conical in shape, with the base of the cone forward; it consists of grey matter, with white substance in its centre, which comes from the corresponding cerebral peduncle. (*b.*) Extraventricular portion (*lenticular nucleus*) is separated from the other portion by a layer of white material. It is seen on section of the hemisphere. Its horizontal section is wider in the centre than at the end. On the outside is the grey lamina (*claustrum*).

Between the corpus striatum and optic thalamus is the *tænia semicircularis*, a semi-transparent band which is continued back into the white substance of the roof of the descending horn of the ventricle.

(2) The Optic Thalami are oval in shape, and rest upon the crura cerebri. The upper surface of each thalamus is free, and of white substance; it projects into the lateral ventricle. The posterior surface is also white. The inner sides of the two optic thalami are in partial contact, and are composed of grey material uncovered by white, and are, as a rule, connected by a transverse portion.

Functions.—The two ganglia, the Corpus Striatum and Optic Thalamus, are placed between the cerebral convolutions and the crus cerebri of the same side. It is probable that although some of the fibres of the crus pass without interruption into the cerebrum, the majority of the fibres pass into these ganglia; first of all the lower fibres (crusta) into the corpus striatum, and the upper (tegmentum) into the optic thalamus, and then out into the cerebrum. From the position of these bodies, it would be reasonable to suppose that they were interposed in function between the operation of the will on the one hand, and on the other with the sensori-motor apparatus below them, and it is believed that this is the case, although the evidence is not exact: the theory that the corpus striatum is the *motor* ganglion, and that, when injured, the communication between the will and the muscles of one half of the body is broken (hemiplegia), being supported by many pathological facts and physiological experiments, and generally received by pathologists. It is found that the cerebral functions are as a rule unimpaired. In the same way the evidence that the optic thalamus is the *sensory* ganglion depends upon similar observations, that when injured or destroyed, sensation of the opposite side of the body is impaired or lost. In both cases, the parts paralyzed are on the opposite side to the lesions, the decussation of both sets of fibres taking place, as we have seen, below the ganglia. It is a fact, however, that many experiments and pathological observations are opposed to the above theory, which must therefore be received with caution.

THE CEREBELLUM.

The Cerebellum (7, 8, 9, 10, Fig. 326), is composed of an elongated central portion called the vermiform processes, and two hemispheres. Each hemisphere is connected with its fellow, not only by means of the vermiform processes, but also by a bundle of fibres called the *middle crus* or *peduncle* (the latter forming the greater part of the pons Varolii), while the *superior crura* with the valve of Vieussens connect it with the cerebrum (5, Fig. 328), and the *inferior crura* (formed by the prolonged restiform bodies) connect it with the medulla oblongata (3, Fig. 328).

Structure.—The cerebellum is composed of white and grey matter, the latter being external, like that of the cerebrum, and like it, infolded, so that a larger area may be contained in a given space. The convolutions of the grey matter, however, are arranged after a different pattern, as shown in Fig. 328. Besides the grey substance on the surface, there is, near the centre of the white substance of each hemisphere, a small capsule of grey matter called the *corpus dentatum* (Fig. 329, *cd*) resembling very closely the *corpus dentatum* of the olivary body of the medulla oblongata (Fig. 324, *o*).

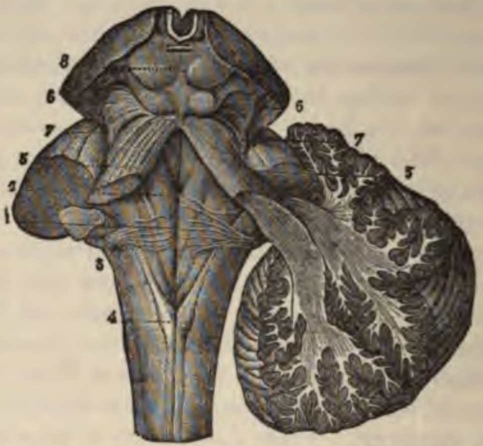


FIG. 328.—Cerebellum in section and of fourth ventricle, with the neighboring parts. 1, median groove of fourth ventricle, ending below in the *calamus scriptorius*, with the longitudinal eminences formed by the *fasciculi teretes*, one on each side; 2, the same groove, at the place where the white streaks of the auditory nerve emerge from it to cross the floor of the ventricle; 3, inferior crus or peduncle of the cerebellum, formed by the restiform body; 4, posterior pyramid; above this is the calamus scriptorius; 5, superior crus of cerebellum, or processus e cerebello ad cerebrum (or ad testes); 6, 6, fillet to the side of the crura cerebri; 7, 7, lateral grooves of the crura cerebri; 8, corpora quadrigemina. (From Sappey after Hirschfeld and Leveillé.)

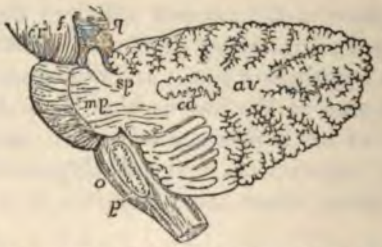


FIG. 329.—Outline sketch of a section of the cerebellum, showing the corpus dentatum. The section has been carried through the left lateral part of the pons, so as to divide the superior peduncle and pass nearly through the middle of the left cerebellar hemisphere. The olivary body has also been divided longitudinally so as to expose in section its *corpus dentatum*. *c r*, crus cerebri; *f*, fillet; *q*, corpora quadrigemina; *s p*, superior peduncle of the cerebellum divided; *m p*, middle peduncle or lateral part of the pons Varolii, with fibres passing from it into the white stem; *a v*, continuation of the white stem radiating toward the arbor vitæ of the folia; *c d*, corpus dentatum; *o*, olivary body with its corpus dentatum; *p*, anterior pyramid. (Allen Thomson.) ⅔.

If a section be taken through the cortical portion of the cerebellum, the following distinct layers can be seen (Fig. 330) by microscopic examination.

(1.) Immediately beneath the pia mater (*p m*) is a layer of considerable thickness, which consists of a delicate connective tissue, in which are scattered several spherical corpuscles like those of the granular layer of the retina, and also an immense number of delicate fibres passing up toward the free surface and branching as they go. These fibres are the processes of the cells of Purkinje. (2.) *The Cells of Purkinje* (*p*). These are a

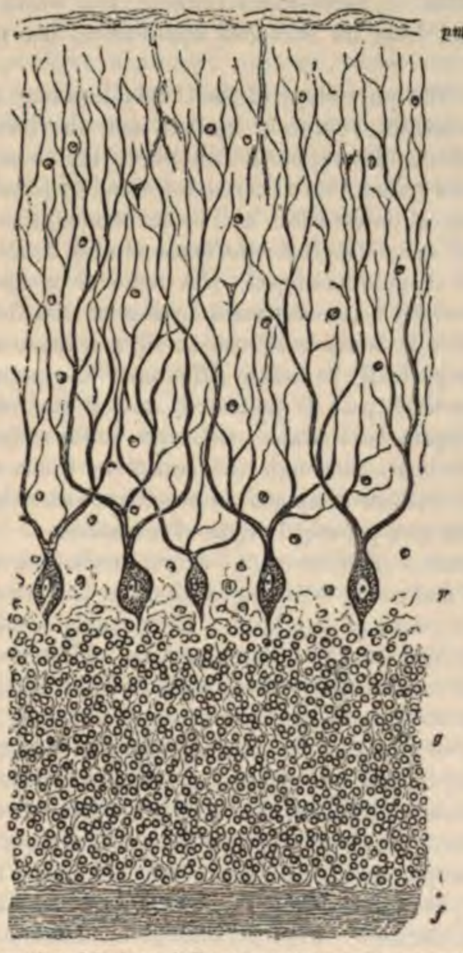


FIG. 330.—Vertical section of dog's cerebellum; *p m*, pia mater; *p*, corpuscles of Purkinje, which are branched nerve-cells lying in a single layer and sending single processes downward and more numerous ones upward, which branch continuously and extend through the deep "molecular layer" toward the free surface; *g*, dense layer of ganglionic corpuscles, closely resembling nuclear layers of retina; *f*, layer of nerve-fibres, with a few scattered ganglionic corpuscles. This last layer (*f f*) constitutes part of the *white* matter of the cerebellum, while the layers between it and the free surface are *grey* matter. (Klein and Noble Smith.)

single layer of branched nerve-cells, which give off a single unbranched process downward, and numerous processes up into the external layer, some of which become continuous with the scattered corpuscles. (3.) *The granular layer* (*g*), consisting of immense numbers of corpuscles closely resembling those of the nuclear layers of the retina. (4.) *Nerve fibre layer* (*f*). Bundles of nerve-fibres forming the white matter of the cerebellum, which, from its branched appearance, has been named the "arbor vitæ."

Functions.—The physiology of the Cerebellum may be considered in its relation to sensation, voluntary motion, and the instincts or higher faculties of the mind. Its supposed functions, like those of every other part of the nervous system, have been determined by physiological experiment, by pathological observation, and by its comparative anatomy.

(1.) *It is itself insensible to irritation,* and may be all cut away without eliciting signs of pain (Longet). Its removal or disorganization by disease is also generally unaccompanied by loss or disorder of sensibility; animals from which it is removed can smell, see, hear, and feel pain, to all appearance, as perfectly as before (Flourens; Magendie). Yet, if any of its crura be touched, pain is indicated; and, if the restiform tracts of the medulla oblongata be irritated, the most acute suffering appears to be produced. So that, although the restiform tracts of the medulla oblongata, which themselves appear so sensitive, enter the cerebellum, it cannot be regarded as a principal organ of sensation.

(2.) *Co-ordination of Movements.*—In reference to motion, the experiments of Longet and many others agree that no irritation of the cerebellum produces movement of any kind. Remarkable results, however, are produced by removing parts of its substance. Flourens (whose experiments have been confirmed by those of Bouillaud, Longet, and others) extirpated the cerebellum in birds by successive layers. Feebleness and want of harmony of muscular movements were the consequence of removing the superficial layers. When he reached the middle layers, the animals became restless without being convulsed; their movements were violent and irregular, but their sight and hearing were perfect. By the time that the last portion of the organ was cut away, the animals had entirely lost the powers of springing, flying, walking, standing, and preserving their equilibrium. When an animal in this state was laid upon its back, it could not recover its former posture, but it fluttered its wings, and did not lie in a state of stupor; it saw the blow that threatened it, and endeavored to avoid it. Volition and sensation, therefore, were not lost, but merely the faculty of combining the actions of the muscles; and the endeavors of the animal to maintain its balance were like those of a drunken man.

The experiments afforded the same results when repeated on all classes of animals; and from them and the others before referred to, Flourens inferred that the cerebellum belongs neither to the sensory nor the intellectual apparatus; and that it is not the source of voluntary movements, although it belongs to the motor apparatus; but is the organ for the co-ordination of the voluntary movements, or for the excitement of the *combined* action of muscles.

Such evidence as can be obtained from cases of disease of this organ confirms the view taken by Flourens; and, on the whole, it gains support from comparative anatomy; animals whose natural movements require most frequent and exact combinations of muscular actions being those whose cerebella are most developed in proportion to the spinal cord.

Foville supposed that the cerebellum is the organ of *muscular sense, i.e.*, the organ by which the mind acquires that knowledge of the actual state and position of the muscles which is essential to the exercise of the will upon them; and it must be admitted that all the facts just referred to are as well explained on this hypothesis as on that of the cerebellum being the organ for combining movements. A harmonious combination of muscular actions must depend as much on the capability of appreciating the condition of the muscles with regard to their tension, and to the force with which they are contracting, as on the power which any special nerve-centre may possess of exciting them to contraction. And it is because the power of such harmonious movement would be equally lost, whether the injury to the cerebellum involved injury to the seat of muscular sense, or to the centre for combining muscular actions, that experiments on the subject afford no proof in one direction more than the other.

The theory once believed, that the cerebellum is the organ of sexual passion, has been long disproved.

Forced Movements.—The influence of each half of the cerebellum is directed to muscles on the opposite side of the body; and it would appear that for the right ordering of movements, the actions of its two halves must be always mutually balanced and adjusted. For if one of its crura, or if the pons on either side of the middle line, be divided, so as to cut off the medulla oblongata and spinal cord the influence of one of the hemispheres of the cerebellum, strangely disordered movements ensue (forced movements). The animals fall down on the side opposite to that on which the crus cerebelli has been divided, and then roll over continuously and repeatedly; the rotation being always round the long axis of their bodies, and generally from the side on which the injury has been inflicted. The rotations sometimes take place with much rapidity; as often, according to Magendie, as sixty times in a minute, and may last for several days. Similar movements have been observed in men; as by Serres in a man in whom there was apoplectic effusion in the right crus cerebelli; and by Belhomme in a woman in whom an exostosis pressed on the left crus. They may, perhaps, be explained by assuming that the division or injury of the crus cerebelli produces paralysis or imperfect and disorderly movements of the opposite side of the body; the animal falls, and then, struggling with the disordered side on the ground, and striving to rise with the other, pushes itself over; and so again and again, with the same act, rotates itself. Such movements cease when the other crus cerebelli is divided; but probably only because the paralysis of the body is thus made almost complete. Other varieties of forced movements have been observed, especially those named "circus movements," when the animal operated upon moves round and round in a circle; and again those in which the animal turns over and over in a series of somersaults. Nearly all these movements may result on section of one or other of the following parts; viz., crura cerebri, medulla, pons, cerebellum, corpora quadrigemina, corpora striata, optic thalami, and even, it is said, of the cerebral hemispheres.

THE CEREBRUM.

The Cerebrum (composed of two so-called *Cerebral hemispheres*) is placed in connection with the Pons and Medulla oblongata by its two *crura* or *peduncles* (III., Fig. 326): it is connected with the cerebellum by the processes called superior crura of the cerebellum, or *processus a cerebello ad testes,* and by a layer of grey matter, called the valve of Vieussens, which lies between these processes, and extends from the inferior vermiform process of the cerebellum to the corpora quadrigemina of the cerebrum. These parts, which thus connect the cerebrum with the other principal divisions of the cerebro-spinal system, may, therefore, be regarded as the continuation of the cerebro-spinal axis or column; on which, as a kind of offset from the main nerve-path, the cerebellum is placed; and on the further continuation of which in the direct line, is placed the cerebrum (Fig. 331).

The Cerebrum is constructed, like the other chief divisions of the cerebro-spinal system, of grey (vesicular and fibrous) and white (fibrous) matter; and, as in the case of the Cerebellum (and unlike the spinal cord and medulla oblongata), the grey matter (*cortex*) is external, and forms a capsule or covering for the white substance. For the evident purpose of increasing its amount without undue occupation of space, the grey matter is variously infolded so as to form the cerebral *convolutions.*

Convolutions of the Cerebrum.—For convenience of description, the surface of the brain has been divided into five lobes (Gratiolet).

1. *Frontal* (F., Figs. 332, 333), limited behind by the fissure of Rolando (central fissure), and beneath by the fissure of Sylvius. Its surface consists of three main convolutions, which are approximately horizontal in direction and are broken up into numerous secondary gyri. They are termed the superior, middle, and inferior frontal convolutions. In addition, the frontal lobe contains, at its posterior part, a convolution which runs upward almost vertically ("ascending frontal"), and is bounded in front by a fissure termed the præcentral, behind by that of Rolando.

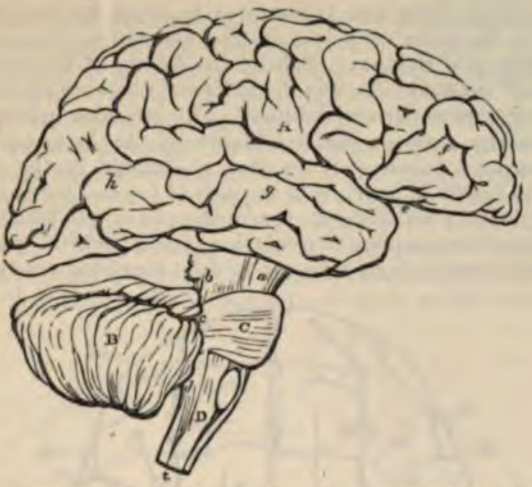


FIG. 331.—Plan in outline of the encephalon, as seen from the right side, ½. The parts are represented as separated from one another somewhat more than natural, so as to show their connections. A, cerebrum; *f*, *g*, *h*, its anterior, middle, and posterior lobes; *e*, fissure of Sylvius; B, cerebellum; C, pons Varolii; D, medulla oblongata; *a*, peduncles of the cerebrum; *b*, *c*, *d*, superior middle, and inferior peduncles of the cerebellum. (From Quain.)

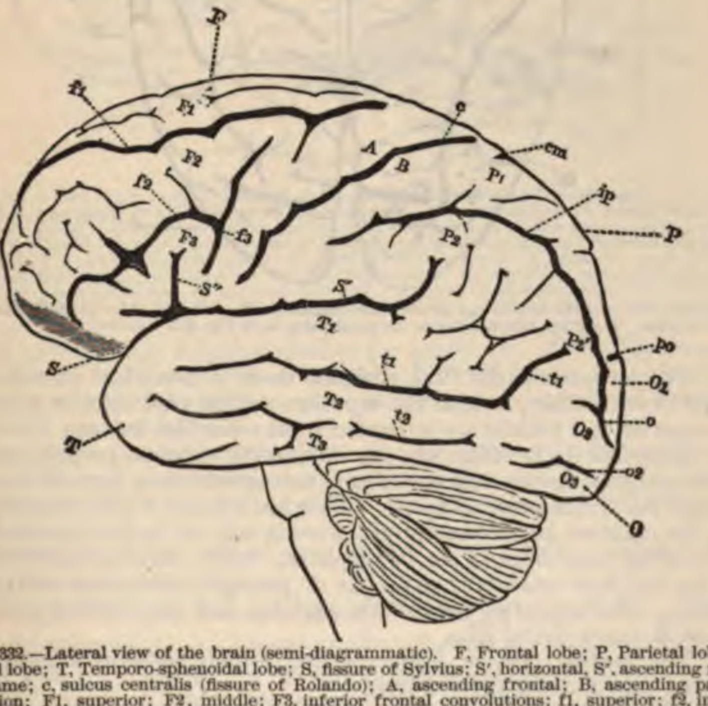


FIG. 332.—Lateral view of the brain (semi-diagrammatic). F, Frontal lobe; P, Parietal lobe; O, Occipital lobe; T, Temporo-sphenoidal lobe; S, fissure of Sylvius; S′, horizontal, S″, ascending ramus of the same; c, sulcus centralis (fissure of Rolando); A, ascending frontal; B, ascending parietal convolution; F1, superior; F2, middle; F3, inferior frontal convolutions; f1, superior; f2, inferior frontal sulcus; f3, præ-central sulcus; P1, superior parietal lobule; P2, inferior parietal lobule consisting of P2, supramarginal gyrus, and P2′, angular gyrus; ip, interparietal sulcus; cm, termination of calloso-marginal fissure; O1, first, O2, second, O3, third occipital convolutions; po, parieto-occipital fissure; o, transverse occipital fissure; o2, sulcus occipitalis inferior; T1, first, T2, second, T3, third temporo-sphenoidal convolutions; t1, first, t2, second temporo-sphenoidal fissures. (Ecker.)

2. *Parietal* (P.). This lobe is bounded in front by the fissure of Rolando, behind by the external perpendicular fissure (parieto-occipital), and below by the fissure of Sylvius. Behind the fissure of Rolando is the "ascending parietal" convolution, which swells out at its upper end into what is termed the superior parietal lobule. The superior parietal lobule is separated from the inferior parietal lobule by the intra-parietal sulcus. The inferior parietal lobule (pli courbe) is situated at the posterior and upper end of the fissure of Sylvius; it consists of (*a*) an anterior part (supramarginal convolution) which hooks round the end of the fissure of Sylvius, and joins the superior temporal convolution, and a posterior part (*b*) (angular gyrus) which hooks round into the middle temporal convolution.

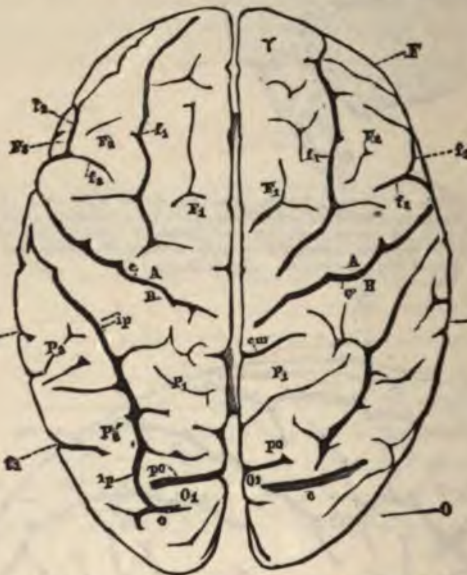


FIG. 333.—View of the brain from above (semi-diagrammatic). Sl, end of horizontal ramus of fissure of Sylvius. The other letters refer to the same parts as in Fig. 332. (Ecker.)

3. *Temporo-sphenoidal* (T.), contains three well-marked convolutions, parallel to each other, termed the superior, middle, and inferior temporal. The superior and middle are separated by the parallel fissure.

4. *Occipital* (O.). This lobe lies behind the external perpendicular or parieto-occipital fissure, and contains three convolutions, termed the superior, middle, and inferior occipital. They are often not well marked. In man, the external parieto-occipital fissure is only to be distinguished as a notch in the inner edge of the hemisphere; below this it is quite obliterated by the four annectent gyri (plis de passage) which run nearly horizontally. The upper two connect the parietal, and the lower two the temporal with the occipital lobe.

5. The *central lobe,* or island of Reil, which contains a number of radiating convolutions (gyri operti).

The *internal* surface (Fig. 334) contains the following gyri and sulci: *Gyrus fornicatus,* a long curved convolution, parallel to and curving round the corpus callosum, and swelling out at its hinder and upper end into the quadrate lobule (præcuneus), which is continuous with the superior parietal lobule on the external surface.

Marginal convolution runs parallel to the preceding, and occupies the space between it and the edge of the longitudinal fissure.

The two convolutions are separated by the calloso-marginal fissure.

The *internal perpendicular* fissure is well marked, and runs downward to its junction with the *calcarine* fissure: the wedge-shaped mass intervening between these two is termed the *cuneus*. The calcarine fissure corresponds to the projection into the posterior cornu of the lateral ventricle, termed the *Hippocampus minor*. The *temporo-sphenoidal lobe* on its internal aspect is seen to end in a hook (uncinate gyrus). The notch round which it curves is continued up and back as the dentate or hippocampal sulcus; this fissure underlies the projection of the hippocampus major within the brain. There are three internal temporo-occipital convolutions, of which the superior and inferior ones are usually well marked, the middle one generally less so.

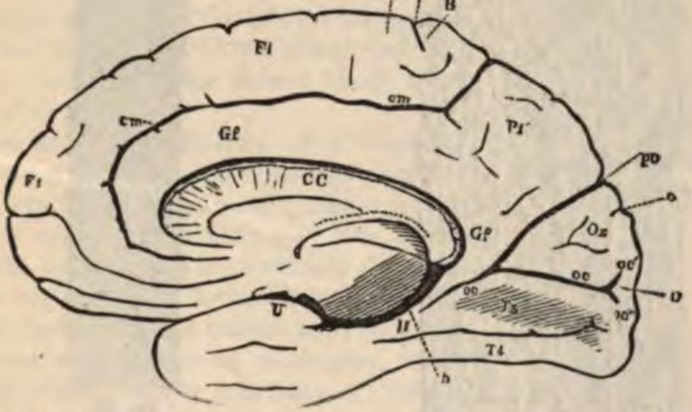


FIG. 334.—View of the right hemisphere in the median aspect (semi-diagrammatic). CC, corpus callosum longitudinally divided; Gf, gyrus fornicatus; H, gyrus hippocampi; h, sulcus hippocampi; U, uncinate gyrus; cm, calloso-marginal fissure; F1, median aspect of first frontal convolution; c, terminal portion of sulcus centralis (fissure of Rolando); A, ascending frontal; B, ascending parietal convolution; P1′, præcuneus; Oz, cuneus; po, parieto-occipital fissure; o, sulcus occipitalis transversus; oc, calcarine fissure; oc′, superior; oc″, inferior ramus of the same; D, gyrus descendens; T4, gyrus occipito-temporalis lateralis (lobulus fusiformis); T5, gyrus occipito-temporalis medialis (lobulus lingualis). (Ecker.)

The collateral fissure (corresponding to the eminentia collateralis) forms the lower boundary of the superior temporo-occipital convolution. All the above details will be found indicated in the diagrams (Fig. 332, 333, 334).

Structure.—The cortical *grey matter* of the brain consists of five layers (Meynert) (Fig. 335).

1. Superficial layer with abundance of neuroglia and a few small multipolar ganglion-cells. 2. A large number of closely packed small ganglion-cells of pyramidal shape. 3. The most important layer, and the thickest of all: it contains many large pyramidal ganglion-cells, each with a process running off from the apex vertically toward the free surface, and lateral processes at the base which are always branched. Also a median process

from the base of each cell which is unbranched and becomes continuous with the axis-cylinder of a nerve-fibre. 4. Numerous ganglion-cells: termed the "granular formation" by Meynert. 5. Spindle-shaped and branched ganglion-cells of moderate size arranged chiefly parallel to the free surface (*vide* Fig. 335).

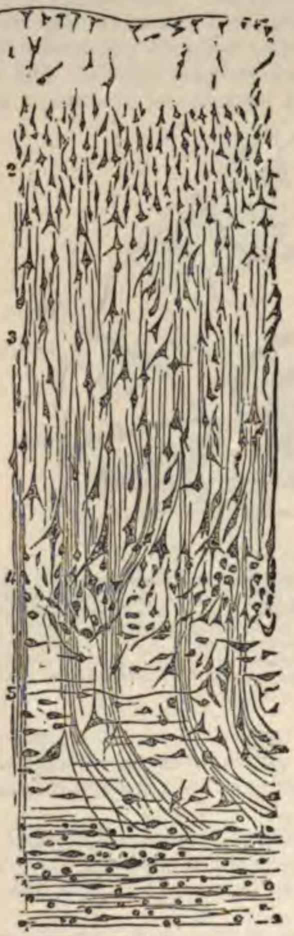


FIG. 335.

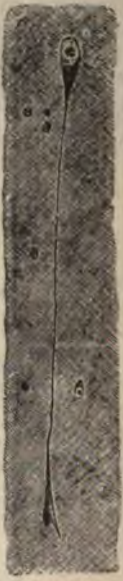


FIG. 336.

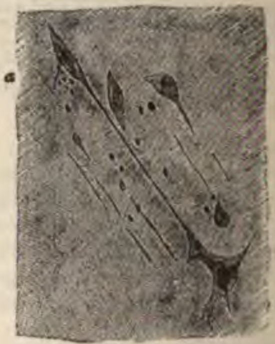


FIG. 337.

FIG. 335.—The layers of the cortical grey matter of the cerebrum. (Meynert.)
FIG. 337.—[Drawn by G. Munro Smith from ammonium bichromate preparations by E. C. Bousfield.]

According to recent observations by Bousfield, the fibres of the medullary centre become connected with the multipolar ganglion cells of the fourth layer, and, from these latter, branches pass to the angles at the bases of the pyramidal cells of the third layer of the cortex (Fig. 337, *a*). From the apices of the pyramidal cells, the axis-cylinder processes pass upward for a considerable distance, and finally terminate in ovoid corpuscles (Fig. 336) closely resembling, and homologous with, the corpuscles in which the ultimate ramifications of the branched cells of Purkinje in the cerebellum terminate. Thus it would seem that the large pyramidal cells of the third layer are themselves homologous with the cells of Purkinje in the cerebellum.

The *white matter* of the brain, as of the spinal cord, consists of bundles of medullated, and, in the neighborhood of the grey matter, of non-medullated nerve-fibres, which, however, as is the case in the central nervous system generally, have no external nucleated nerve-sheath, which are held together by delicate connective tissue. The size of the fibres of the brain is usually less than that of the fibres of the spinal cord: the average diameter of the former being about $\frac{1}{10000}$ of an inch.

Chemical Composition.—The chemistry of nerve and nerve cells has been chiefly studied in the brain and spinal cord. Nerve matter contains several albuminous and fatty bodies (cerebrin, lecithin, and some others), also fatty matter which can be extracted by ether (including cholesterin) and various salts, especially Potassium and Magnesium phosphates, which exist in larger quantity than those of Sodium and Calcium. Yolk of egg resembles cerebral substance very closely in its chemical composition; milk and muscle also come very near it.

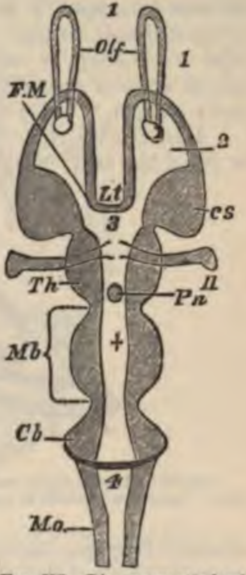


FIG. 338.—Diagrammatic horizontal section of a Vertebrate brain. The figures serve both for this and the next diagram. *Mb*, mid brain: what lies in front of this is the fore, and what lies behind, the hind brain; *Lt*, lamina terminalis; *Olf*, olfactory lobes; *Hmp*, hemispheres; *Th. E*, thalamencephalon; *Pn*, pineal gland; *Py*, pituitary body; *F.M*, foramen of Munro; *cs*, corpus striatum; *Th*, optic thalamus; *CC*, crura cerebri: the mass lying above the canal represents the corpora quadrigemina; *Cb*, cerebellum; *I–IX.*, the nine pairs of cranial nerves; 1, olfactory ventricle; 2, lateral ventricle; 3, third ventricle; 4, fourth ventricle; +, iter a tertio ad quartum ventriculum. (Huxley.)

The great relative and absolute size of the Cerebral hemispheres in the adult man, masks to a great extent the real arrangement of the several parts of the brain, which is illustrated in the two accompanying diagrams. From these it is apparent that the parts of the brain are disposed in a linear series, as follows (from before backward): olfactory lobes, cerebral hemispheres, optic thalami, and third ventricle, corpora quadrigemina, or optic lobes, cerebellum, medulla oblongata.

This linear arrangement of parts actually occurs in the human fœtus (see Chapter on Development), and it is permanent in some of the lower Vertebrata, *e.g.*, Fishes, in which the cerebral hemispheres are represented by a pair of ganglia intervening between the olfactory and the optic lobes, and considerably smaller than the latter. In Amphibia the cerebral lobes are further developed, and are larger than any of the other ganglia.

In Reptiles and Birds the cerebral ganglia attain a still further development, and in Mammalia the cerebral hemispheres exceed in weight all the rest of the brain. As we ascend the scale, the relative size of the cerebrum increases, till in the higher apes and man the hemispheres, which commenced as two little lateral buds from the anterior cerebral vesicle, have grown upward and backward, completely covering in and hiding from view all the rest of the brain. At the same time the smooth surface of the brain, in many lower Mammalia, such as the rabbit, is replaced by the labyrinth of convolutions of the human brain.

Weight of the Brain.—The brain of an adult man weighs from 48 to 50 oz.—or about 3 lbs. It exceeds in absolute weight that of all the lower animals except the elephant and whale. Its weight, *relatively to that of the body,* is only exceeded by that of a few small birds and some of the smaller monkeys. In the adult man it ranges from $\frac{1}{30}$—$\frac{1}{50}$ of the body weight.

Variations. Age.—In a new-born child the brain (weighing 10—14 oz.) is $\frac{1}{10}$ of the body weight. At the age of 7 years the weight of the brain already averages 40 oz., and about 14 years the brain not unfrequently reaches the weight of 48 oz. Beyond the age of 40 years the weight slowly but steadily declines at the rate of about 1 oz. in 10 years.

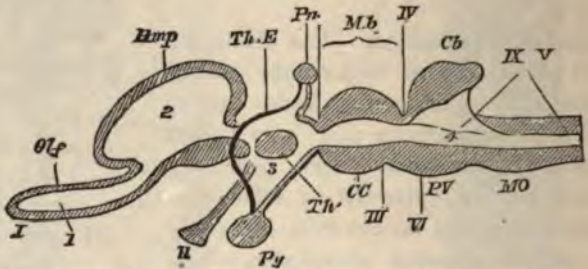


FIG. 339.—Longitudinal and, vertical Diagrammatic section of a Vertebrate brain. Letters as before. Lamina terminalis is represented by the strong black line joining *Pn* and *Py*. (Huxley.)

Sex.—The average weight of the female brain is less than the male; and this difference persists from birth throughout life. In the adult it amounts to about 5 oz. Thus the average weight of an adult woman's brain is about 44 oz.

Intelligence.—The brains of idiots are generally much below the average, some weighing less than 16 oz. Still the facts at present collected do not warrant more than a very general statement, to which there are numerous exceptions, that the brain weight corresponds to some extent with the degree of intelligence. There can be little doubt that the *complexity* and *depth* of the convolutions, which indicate the area of the grey matter of the cortex, correspond with the degree of intelligence (R. Wagner).

Weight of the Spinal Cord.—The *spinal cord* of man weighs from 1—1½ oz.; its weight relatively to the brain is about 1 : 36. As we descend the scale, this ratio constantly increases till in the mouse it is 1 : 4. In cold-blooded animals the relation is reversed, the spinal cord is the heavier and more important organ. In the newt, 2 : 1; and in the lamprey, 75 : 1.

Distinctive Characters of the Human Brain.—The following character distinguish *the brain of man and apes from those of all other animals.* (*a.*)

The rudimentary condition of the olfactory lobes. (*b*). A perfectly defined fissure of Sylvius. (*c*). A posterior lobe completely covering the cerebellum. (*d*). The presence of posterior cornua in the lateral ventricles (Gratiolet).

The most *distinctive points in the human brain*, as contrasted with that of apes, are:—(1). The much greater size and weight of the whole brain. The brain of a full-grown gorilla weighs only about 15 oz., which is less than ⅓ the weight of the human adult male brain, and barely exceeds that of the human infant at birth. (2). The much greater complexity of the convolutions, especially the existence in the human brain of tertiary convolutions in the sides of the fissures. (3). The greater relative size and complexity, and the blunted quadrangular contour of the frontal lobes in man, which are relatively both broader, longer, and higher, than in apes. In apes the frontal lobes project keel-like (rostrum) between the olfactory bulbs. (4). The much greater prominence of the temporo-sphenoidal lobe in apes. (5). The fissure of Sylvius is nearly horizontal in man, while in apes it slants considerably upward. (6). The distinctness of the external perpendicular fissure, which in apes is a well-defined almost vertical "slash," while in man it is almost obscured by the annectent gyri (Rolleston).

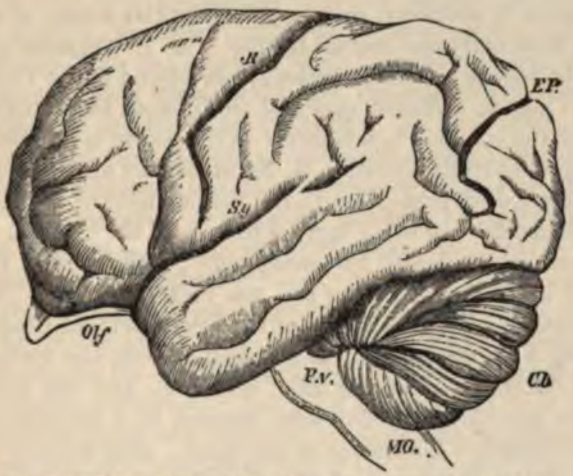


FIG. 340.—Brain of the Orang, ⅔ natural size, showing the arrangement of the convolutions. *Sy*, fissure of Sylvius; *R*, fissure of Rolando; *EP*, external perpendicular fissure; *Olf*, olfactory lobe; *Cb*, cerebellum; *PV*, pons Varolii; *MO*, medulla oblongata. As contrasted with the human brain, the frontal lobe is short and small relatively, the fissure of Sylvius is oblique, the temporo-sphenoidal lobe very prominent, and the external perpendicular fissure very well marked. (Gratiolet.)

Most of the above points are shown in the accompanying figure of the brain of the Orang.

Functions.—(1.) The Cerebral hemispheres are the organs by which are perceived those clear and more impressive sensations which can be retained, and regarding which we can judge. (2.) The Cerebrum is the organ of the will in so far at least as each act of the will requires a deliberate, however quick determination. (3.) It is the means of retaining impressions of sensible things, and reproducing them in subjective sensations and ideas. (4.) It is the medium of all the higher emotions and feelings, and of the faculties of judgment, understanding, memory, reflection, induction, imagination and the like.

Evidence regarding the physiology of the cerebral hemispheres has been obtained, as in the case of other parts of the nervous system, from the study of Comparative Anatómy, from Pathology, and from Experiments on the lower animals. The chief evidences regarding the functions of the Cerebral hemispheres derived from these various sources, are briefly these:—1. Any severe injury of them, such as a general concussion, or sudden pressure by apoplexy, may instantly deprive a man of all power of manifesting externally any mental faculty. 2. In the same general proportion as the higher mental faculties are developed in the Vertebrate animals, and in man at different ages and in different individuals, the more is the size of the cerebral hemispheres developed in comparison with the rest of the cerebro-spinal system. 3. No other part of the nervous system bears a corresponding proportion to the development of the mental faculties. 4. Congenital and other morbid defects of the cerebral hemisphere are, in general, accompanied by corresponding deficiency in the range or power of the intellectual faculties and the higher instincts. 5. Removal of the cerebral hemispheres in one of the lower animals produces effects corresponding with what might be anticipated from the foregoing facts. The animal, although retaining mere sensation, and the power of performing even complicated reflex acts, remains in a state of stupor, and performs no voluntary movement of any kind. (See below.)

Effects of the Removal of the Cerebrum.—The removal of the cerebrum in the lower animals appears to reduce them to the condition of a mechanism without spontaneity. A pigeon from which the cerebrum has been removed will remain motionless and apparently unconscious unless disturbed. When disturbed in any way it soon recovers its former position; when thrown into the air it flies.

In the case of the frog, when the cerebral lobes have been removed, the animal appears similarly deprived of all power of spontaneous movement. But it sits up in a natural attitude, breathing quietly; when pricked it jumps away; when thrown into the water it swims; when placed upon the palm of the hand it remains motionless, although, if the hand be gradually tilted over till the frog is on the point of losing his balance, he will crawl up till he regains his equilibrium, and comes to be perched quite on the edge of the hand. This condition contrasts with that resulting from the removal of the entire brain, leaving only the spinal cord; in this case only the simpler reflex actions can take place. The frog does not breathe, he lies flat on the table instead of sitting up; when thrown into a vessel of water he sinks to the bottom; when his legs are pinched he kicks out, but does not leap away.

Unilateral action.—Respecting the mode in which the brain discharges its functions, there is no evidence whatever. But it appears that, for all but its highest intellectual acts, one of the cerebral hemispheres is sufficient. For numerous cases are recorded in which no mental defect was observed, although one cerebral hemisphere was so disorganized or atrophied that it could not be supposed capable of discharging its functions. The remaining hemisphere was, in these cases, adequate to the functions generally discharged by both; but the mind does not seem in any of these cases to have been tested in very high intellectual exercises; so that it is not certain that one hemisphere will suffice for these. In general, the mind combines, as one sensation, the impressions which it derives from one object through both hemispheres, and the ideas to which the two such impressions give rise are single. In relation to common sensation and the effort of the will, the impressions to and from the hemispheres of the brain are carried across the middle line; so that in destruction or compression of either hemisphere, whatever effects are produced in loss of sensation or voluntary motion, are observed on the side of the body opposite to that on which the brain is injured.

Localization of Functions.—In speaking of the cerebral hemispheres as the so-called organs of the mind, they have been regarded as if they were single organs, of which all parts are equally appropriate for the exercise of each of the mental faculties. But it is possible that each faculty has a special portion of the brain appropriated to it as its proper organ. For this theory the principal evidences are as follows:—1. That it is in accordance with the physiology of the compound organs or systems in the body, in which each part has its special function; as, for example, of the digestive system, in which the stomach, liver, and other organs perform each their separate share in the general process of the digestion of the food. 2. That in different individuals the several mental functions are manifested in very different degrees. Even in early childhood, before education can be imagined to have exercised any influence on the mind, children exhibit various dispositions—each presents some predominant propensity, or evinces a singular aptness in some study or pursuit; and it is a matter of daily observation that every one has his peculiar talent or propensity. But it is difficult to imagine how this could be the case, if the manifestation of each faculty depended on the whole of the brain; different conditions of the whole mass might affect the mind generally, depressing or exalting all its functions in an equal degree, but could not permit one faculty to be strongly and another weakly manifested. 3. The plurality of organs in the brain is supported by the phenomena of some forms of mental derangement. It is not usual for all the mental faculties in an insane person to be equally disordered; it often happens that the strength of some is increased, while that of others is diminished; and in many cases one function only of the brain is deranged, while all the rest are performed in a natural manner. 4. The same opinion is supported by the fact that the several mental faculties are developed to their greatest strength at different periods of life, some being exercised with great energy in childhood, others only in adult age; and that, as their energy decreases in old age, there is not a gradual and equal diminution of power in all of them at once, but, on the contrary, a diminution in one or more, while others retain their full strength, or even increase in power. 5. The plurality of cerebral organs appears to be indicated by the phenomena of dreams, in which only a part of the mental faculties are at rest or asleep, while the others are awake, and, it is presumed, are exercised through the medium of the parts of the brain appropriated to them.

Unconscious Cerebration.—In connection with the above, some remarkable phenomena should be mentioned which have been described as depending on an *unconscious* action of the brain.

It must be within the experience of every one to have tried to recollect some particular name or occurrence: and after trying in vain for some time the attempt is given up and quite forgotten amid other occupations, when suddenly, hours or even a day or two afterward, the desired name or occurrence unexpectedly flashes across the mind. Such occurrences are supposed by many to be due to the requisite cerebral processes going on unconsciously, and, when the result is reached, to our all at once becoming conscious of it.

That *unconscious cerebration* may sometimes occur, is likely enough; and it is paralleled by the unconscious walking of a somnambulist. But many cases of so-called unconscious cerebration are better explained by the supposition that some missing link in the chain of reasoning cannot at the moment be found; but is afterward, by some chance combination of events, suggested, and thus the mental process is at once, with the memory of what has gone before, completed.

Again, in the vain endeavor to solve a difficult or it may be an easy problem, the reasoner is frequently in the condition of a man whose wearied muscles could never, before they have rested, overcome some obstacles. In both cases,—of brain and muscle, after renewal of their textures by rest, the task is performed so rapidly as to seem instantaneous.

Aphasia.—From the apparently greater frequency of interference with the faculty of speech in disease of the *left* than of the *right* half of the cerebrum, it has been thought that the nerve-centre for *language*, including in this term all articulate expression of ideas, is situated in the *left* cerebral hemisphere. A large number of cases are on record in which *aphasia*, or the loss of power of expressing ideas in words, has been associated with disease of the posterior part of the lower or third frontal convolution on the left side. This condition is usually associated with paralysis of the right side (right hemiplegia). The only conclusion, however, which can be drawn from this, is, that the integrity of this particular convolution is essential to the faculty of speech; we cannot conclude that it is necessarily the *centre* for language. It may be only one link in the complete chain of nervous connections necessary for the translation of an idea into articulate expression.

It seems highly probable that the corresponding right convolutions can take on the same functions as the left; and it is in this way that we can explain those cases in which recovery of speech takes place, though the *left* frontal convolution still remains diseased.

Pineal and Pituitary Bodies.

Nothing is known of the function of the pineal and pituitary bodies. They have been, indeed, supposed by some to be rather ductless glands than nervous organs (p. 10, Vol. II.).

Experimental Localizations.—Attempts have been made to localize cerebral functions by means of experiments on the lower animals. It had long been well known that the cerebral hemispheres could not be excited by mechanical, chemical, or thermal stimuli, but Fritsch and Hitzig were the first to show that they are amenable to electric irritation. They employed a weak constant current in their experiments, applying a pair of fine electrodes not more than $\frac{1}{12}$ in. apart to different parts of the cerebral cortex. The results thus obtained have been confirmed and extended by Ferrier.

The following are the fundamental phenomena observed in all these cases:

(1.) Excitation of the same spot is always followed by the same movement in the same animal. (2.) The area of excitability for any given movement is extremely small, and admits of very accurate definition. (3.) In different animals excitations of anatomically corresponding spots produce similar or corresponding results (Burdon-Sanderson).

The various definite movements resulting from the electric stimulation of circumscribed areas of the cerebral cortex, are enumerated in the description of the accompanying figures of the dog and monkey's brain.

In the case of the dog, the results obtained are summed up as follows, by Hitzig.

(*a.*) One portion (anterior) of the convexity of the cerebrum is motor; another portion (posterior) is non motor. (*b.*) Electric stimulation of the motor portion produces co-ordinated muscular contraction on the opposite side of the body. (*c.*) With very weak currents, the contractions produced are distinctly limited to particular groups of muscles; with stronger currents the stimulus is communicated to other muscles of the same or neighboring parts. (*d.*) The portions of the brain intervening between these motor centres are inexcitable by similar means.

With regard to the facts above mentioned, all experimenters are agreed, but there is still considerable diversity of opinion as to their explanation.

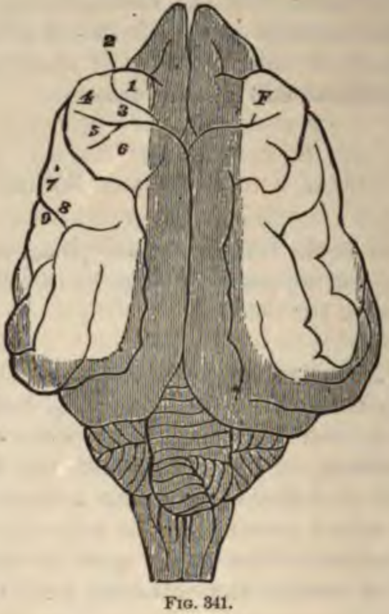
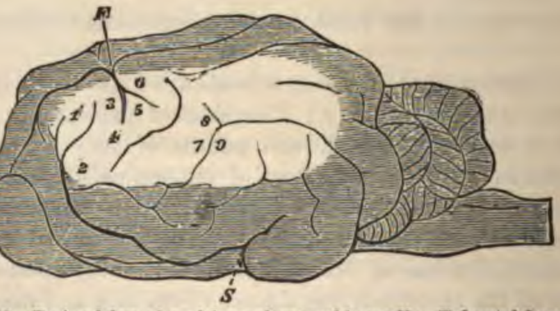


FIG. 341.



FIGS. 341 and 342.—Brain of dog, viewed from above and in profile. *F*, frontal fissure, sometimes termed crucial sulcus, corresponding to the fissure of Rolando in man; *S*, fissure of Sylvius, around which the four longitudinal convolutions are concentrically arranged; 1, flexion of head on the neck, in the median line; 2, flexion of head on the neck, with rotation toward the side of the stimulus; 3, 4, flexion and extension of anterior limb; 5, 6, flexion and extension of posterior limb; 7, 8, 9, contraction of orbicularis oculi, and the facial muscles in general. The unshaded part is that exposed by opening the skull. (Dalton.)

It is evident that the spots marked out on the cortex are not strictly speaking motor *centres*, for they can be removed entirely without destroying the power of voluntary motion.

Burdon-Sanderson has shown that electric stimulation of different points in a horizontal section, through the deeper parts of the hemispheres, produces the same effects as stimulation of the so-called "centres" in the grey matter overlying them: while the same results follow electric stimulation of different points of the corpus striatum.

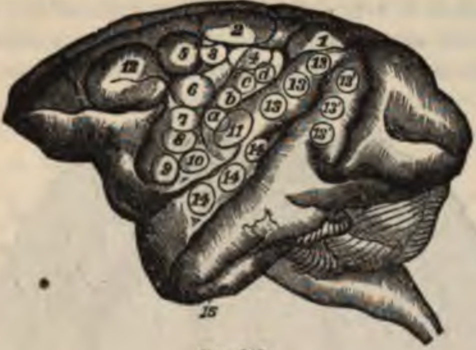


Fig. 343.

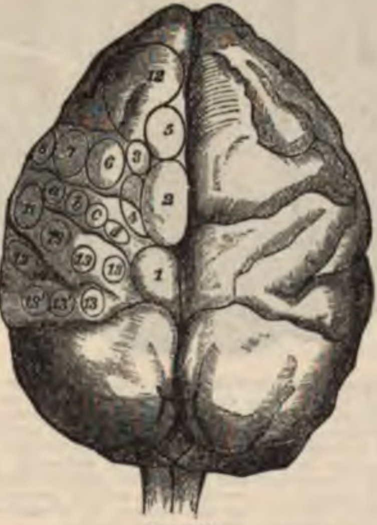


Fig. 344.

Figs. 343 and 344.—Diagrams of monkey's brain to show the effects of electric stimulation of certain spots. 1, movement of hind foot; 2, chiefly adduction of foot; 3, movements of hind foot and tail; 4, of latissimus dorsi; 5, extension forward of arm; *a*, *b*, *c*, *d*, movements of hand and wrist; 6, supination and flexion of forearm; 7, elevation of upper lip; 8, conjoint action of elevation of upper lip and depression of lower; 9, opening of mouth and protrusion of tongue; 10, retraction of tongue; 11, action of platysma; 12, elevation of eyebrows and eyelids, dilatation of pupils, and turning head to opposite side; 13, eyes directed to opposite side and upward, with usually contraction of the pupils; 13′, similar action, but eyes usually directed downward; 14, retraction of opposite ear, head turns to the opposite side, the eyes widely opened and pupils dilated; 15, stimulation of this region, which corresponds to the tip of the uncinate convolution, causes torsion of the lip and nostril of the same side. (Ferrier.)

In applying the facts ascertained by these experiments to elucidate the physiology of the human brain, we must remember that the method of electric stimulation is an artificial one, differing widely from the ordinary stimuli to which the brain is subject during life.

Functions of other Parts of the Brain.—Of the physiology of the other parts of the brain, little or nothing can be said.

Of the offices of the *corpus callosum*, or great transverse and oblique commissure of the brain, nothing positive is known. But instances in which it was absent, or very deficient, either without any evident mental defect, or with only such as might be ascribed to coincident affections of other parts, make it probable that the office which is commonly assigned to it, of enabling the two sides of the brain to act in concord, is exercised only in the highest acts of which the mind is capable. And this view is confirmed by the very late period of its development, and by its very rudimentary condition (Flower) in all but the placental Mammalia.

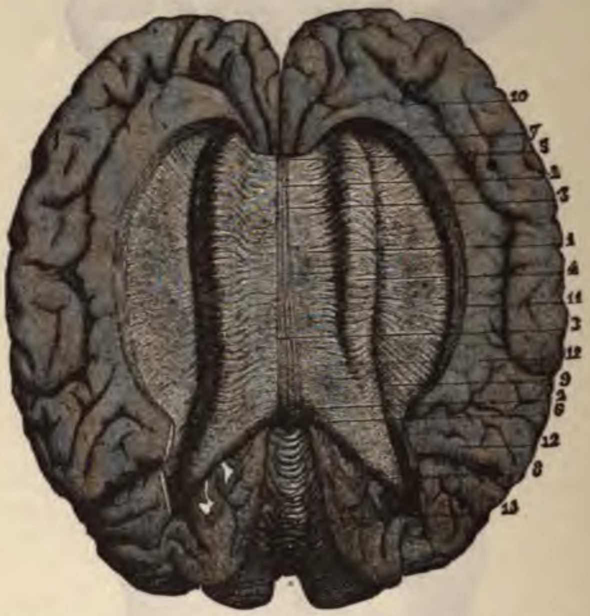


FIG. 345.—View of the corpus callosum from above. ½.—The upper surface of the corpus callosum has been fully exposed by separating the cerebral hemispheres and throwing them to the side; the gyrus fornicatus has been detached, and the transverse fibres of the corpus callosum traced for some distance into the cerebral medullary substance. 1, the upper surface of the corpus callosum; 2, median furrow or raphe; 3, longitudinal striæ bounding the furrow; 4, swelling formed by the transverse bands as they pass into the cerebrum; 5, anterior extremity or knee of the corpus callosum; 6, posterior extremity; 7, anterior, and 8, posterior part of the mass of fibres proceeding from the corpus callosum; 9, margin of the swelling; 10, anterior part of the convolution of the corpus callosum; 11, hem or band of union of this convolution; 12, internal convolutions of the parietal lobe; 13, upper surface of the cerebellum. (Sappey after Foville.)

To the fornix and other commissures no special function can be assigned; but it is a reasonable hypothesis that they connect the action of the parts between which they are severally placed.

SLEEP.

All parts of the body which are the seat of active change require periods of rest. The alternation of work and rest is a necessary condition of their maintenance and of the healthy performance of their functions. These alternating periods, however, differ much in duration in different cases; but, for any individual instance, they preserve a general and rather close uniformity. Thus, as before mentioned, the periods of rest and work, in the case of the heart, occupy, each of them, about half a second; in the case of the ordinary respiratory muscles the periods are about four or five times as long. In many cases, again (as of the voluntary muscles during violent exercise), while the periods during active exertion alternate very frequently, yet the expenditure goes far ahead of the repair, and, to compensate for this, an after repose of some hours becomes necessary; the rhythm being less perfect as to *time*, than in the case of the muscles concerned in circulation and respiration.

Obviously, it would be impossible that, in the case of the Brain, there should be short periods of activity and repose, or in other words, of consciousness and unconsciousness. The repose must occur at long intervals; and it must therefore be proportionately long. Hence the necessity for that condition which we call *Sleep;* a condition which, seeming at first sight exceptional, is only an unusually perfect example of what occurs, at varying intervals, in every actively working portion of our bodies.

A temporary abrogation of the functions of the cerebrum imitating sleep, may occur, in the case of injury or disease, as the consequence of two apparently widely different conditions. Insensibility is equally produced by a *deficient* and an *excessive* quantity of blood within the cranium, (coma); but it was once supposed that the latter offered the truest analogy to the normal condition of the brain in sleep, and in the absence of any proof to the contrary, the brain was said to be during sleep *congested.* Direct experimental enquiry has led, however, to the opposite conclusion.

By exposing, at a circumscribed spot, the surface of the brain of living animals, and protecting the exposed part by a watch-glass, Durham was able to prove that the brain becomes visibly paler (anæmic) during sleep; and the anæmia of the optic disc during sleep, observed by Hughlings Jackson, may be taken as a strong confirmation, by analogy, of the same fact.

A very little consideration will show that these experimental results correspond exactly with what might have been foretold from the analogy of other physiological conditions. Blood is supplied to the brain for two partly distinct purposes. (1.) It is supplied for mere nutrition's sake. (2.) It is necessary for bringing supplies of potential or active energy, (*i.e., combustible matter* or *heat*) which may be transformed by the cerebral corpuscles into the various manifestations of nerve-force. During sleep, blood is requisite for only the first of these purposes; and its supply in greater quantity would be not only useless, but, by supplying an excitement to work, when rest is needed, would be positively harmful. In this respect the varying circulation of blood in the brain exactly resembles that which occurs in all other energy transforming parts of the body; *e.g., glands* or *muscles.*

At the same time, it is necessary to remember that the normal anæmia of the brain which accompanies sleep is probably a result and not a cause of the quiescence of the cerebral functions. What the immediate cause of this periodical partial abrogation of function is, however, we do not know.

Somnambulism and Dreams.—What we term *sleep* occurs often in very different degrees in different parts of the nervous system; and in some parts the expression cannot be used in the ordinary sense.

The phenomena of *dreams* and *somnambulism* are examples of differing degrees of sleep in different parts of the cerebro-spinal nervous system. In the former case the cerebrum is still partially active; but the mind-products of its action are no longer corrected by the reception, on the part of the sleeping *sensorium,* of impressions of objects belonging to the outer world; neither can the cerebrum, in this half-awake condition, act on the centres of reflex action of the voluntary muscles, so as to cause the latter to contract—a fact within the painful experience of all who have suffered from nightmare.

In somnambulism the cerebrum is capable of exciting that train of reflex nervous action which is necessary for progression, while the nerve-centre of *muscular sense* (in the cerebellum?) is, presumably, fully awake; but the *sensorium* is still asleep, and impressions made on it are not sufficiently *felt* to rouse the cerebrum to a comparison of the difference between mere ideas or memories and sensations derived from external objects.

PHYSIOLOGY OF THE CRANIAL NERVES.

The *cranial* nerves are commonly enumerated as nine pairs; but the number is in reality twelve, the seventh nerve consisting as it does, of two nerves, and the eighth of three. All arise (superficial origin) from the base of the encephalon, in a double series which extends from the under surface of the anterior cerebral lobes to the lower end of the medulla oblongata. Traced into the substance of the brain and medulla, the roots of the nerves are found connected with various masses of grey matter, which are all connected one with another, and with the cerebral hemispheres.

The roots of the olfactory *tracts* are connected deeply with the cortex of the anterior cerebral hemisphere, and probably with the corpora striata also. The optic nerves can be traced into the optic thalami, corpora quadrigemina, and corpora geniculata. The third and fourth nerves arise from grey matter beneath the corpora quadrigemina; and the roots of origin of the remainder of the cranial nerves can be traced to grey matter in the medulla oblongata beneath the floor of the fourth ventricle, and in the more central part of the medulla, around its central canal, as low down as the decussation of the pyramids.

According to their several functions, the cranial nerves may be thus arranged:—

Nerves of special sense . .	Olfactory, optic, auditory, part of the glosso-pharyngeal, and of the lingual branch of the fifth.
" of common sensation .	The greater portion of the fifth.
" of motion	Third, fourth, lesser division of the fifth, sixth, facial, and hypoglossal.
Mixed nerves	Glossopharyngeal, vagus, and spinal accessory.

The physiology of the several nerves of the special senses will be considered with the organs of those senses.

THIRD NERVE.

Functions.—The third nerve, or *motor oculi*, supplies the levator palpebræ superioris muscle, and, of the muscles of the eyeball, all but the superior oblique or trochlearis, to which the fourth nerve is appropriated, and the rectus externus which receives the sixth nerve. Through the medium of the ophthalmic or lenticular ganglion, of which it forms what is called the short root, it also supplies motor filaments to the iris and ciliary muscle.

When the third nerve is irritated within the skull, all those muscles to which it is distributed are convulsed. When it is *paralyzed* or *divided* the following effects ensue: (1), the upper eyelid can be no longer raised by the elevator palpebræ, but droops (ptosis) and remains gently closed over the eye, under the unbalanced influence of the orbicularis palpebrarum, which is supplied by the facial nerve: (2), the eye is turned outward (external strabismus) by the unbalanced action of the rectus externus, to which the sixth nerve is appropriated: and hence, from the irregularity of the axes of the eyes, double-sight is often experienced when a single object is within view of both the eyes: (3), the eye cannot be moved either upward, downward, or inward: (4), the pupil becomes dilated (mydriasis), and insensible to light: (5), the eye cannot "accommodate" itself for vision at short distances.

Contraction and Dilatation of the Pupil.—The relation of the third nerve to the iris is of peculiar interest. In ordinary circumstances the contraction of the iris is a reflex action, which may be explained as produced by the stimulus of light on the retina being conveyed by the optic nerve to the brain (probably to the corpora quadrigemina), and thence reflected through the third nerve to the iris. Hence the iris ceases to act when either the optic or the third nerve is divided or destroyed, or when the corpora quadrigemina are destroyed or much compressed. But when the optic nerve is divided, the contraction of the iris may be excited by irritating that portion of the nerve which is connected with the brain: and when the third nerve is divided, the irritation of its distal portion will still excite the contraction of the iris.

The contraction of the iris thus shows all the characters of a reflex act, and in ordinary cases requires the concurrent action of the optic nerve, corpora quadrigemina, and third nerve; and, probably also, considering the peculiarities of its perfect mode of action, of the ophthalmic ganglion. But, besides, both irides will contract their pupils under the reflected stimulus of light falling only on one retina or under irritation of one optic nerve. Thus, in blindness of one eye, its pupil may contract when the other eye is exposed to a stronger light: and generally the contraction of each of the pupils appears to be in direct proportion to the total quantity of light which stimulates either one or both retinæ, according as one or both eyes are open.

The iris acts also in association with certain other muscles supplied by the third nerve: thus, when the eye is directed inward, or upward and inward, by the action of the third nerve distributed in the rectus internus and rectus superior, the iris contracts, as if under direct voluntary influence. The will cannot, however, act on the iris alone through the third nerve; but this aptness to contract in association with the other muscles supplied by the third, may be sufficient to make it act even in total blindness and insensibility of the retina, whenever these muscles are contracted. The contraction of the pupils, when the eyes are moved inward, as in looking at a near object, has probably the purpose of excluding those outermost rays of light which would be too far divergent to be refracted to a clear image on the retina; and the dilatation in looking straight forward as in looking at a distant object, permits the admission of the largest number of rays, of which none are too divergent to be so refracted. (For further remarks on the contraction and dilatation of the pupil, see pp. 205, 206, Vol. II.)

FOURTH NERVE.

Functions.—The fourth nerve, or *Nervus trochlearis* or *patheticus*, is exclusively motor, and supplies only the trochlearis or obliquus superior muscle of the eyeball.

FIFTH OR TRIGEMINAL NERVE.

Functions.—The fifth or trigeminal nerve resembles, as already stated, the spinal nerves, in that its branches are derived through two roots; namely, the larger or *sensory*, in connection with which is the Gasserian ganglion, and the smaller or *motor* root which has no ganglion, and which passes under the ganglion of the sensory root to join the third branch or division which issues from it. The first and second divisions of the nerve, which arise wholly from the larger root, are purely sensory. The third division being joined, as before said, by the motor root of the nerve, is of course both motor and sensory.

(a.) **Motor Functions.**—Through branches of the lesser or non-ganglionic portion of the fifth, the muscles of mastication, namely, the temporal, masseter, two pterygoid, anterior part of the digastric, and mylo-hyoid, derive their motor nerves. Filaments are also supplied to the tensor tympani and tensor palati. The motor function of these branches is proved by the violent contraction of all the muscles of mastication in experimental irritation of the third or inferior maxillary division of the nerve; by paralysis of the same muscles, when it is divided or disorganized, or from any reason deprived of power; and by the retention of the power of these muscles, when all those supplied by the facial nerve lose their power through paralysis of that nerve. The last instance proves best, that though the buccinator muscle gives passage to, and receives some filaments from, a buccal branch of the inferior division of the fifth nerve, yet it derives its motor power from the facial, for it is paralyzed together with the other muscles that are supplied by the facial, but retains its power when the other muscles of mastication are paralyzed. Whether, however, the branch of the fifth nerve which is supplied to the buccinator muscle is entirely sensory, or in part motor also, must remain for the present doubtful. From the fact that this muscle, besides its other functions, acts in concert or harmony with the muscles of mastication, in keeping the food between the teeth, it might be supposed from analogy, that it would have a motor branch from the same nerve that supplies them. There can be no doubt, however, that the so-called buccal branch of the fifth is, in the main, sensory; although it is not quite certain that it does not give a few motor filaments to the buccinator muscle.

(b.) **Sensory Functions.**—Through the branches of the greater or ganglionic portion of the fifth nerve, all the anterior and antero-lateral parts of the face and head, with the exception of the skin of the parotid region (which derives branches from the cervical spinal nerves), acquire common sensibility; and among these parts may be included the organs of special sense, from which common sensations are conveyed through the fifth nerve, and their special sensations through their several nerves of special sense. The muscles, also, of the face and lower jaw acquire muscular sensibility, through the filaments of the ganglionic portion of the fifth nerve distributed to them with their proper motor nerves. The sensory function of the branches of the greater division of the fifth nerve is proved, by all the usual evidences, such as their distribution in parts that are sensitive and not capable of muscular contraction, the exceeding sensibility of some of these parts, their loss of sensation when the nerve is paralyzed or divided, the pain without convulsions produced by morbid or experimental irritation of the trunk or branches of the nerve, and the analogy of this portion of the fifth to the posterior root of the spinal nerve.

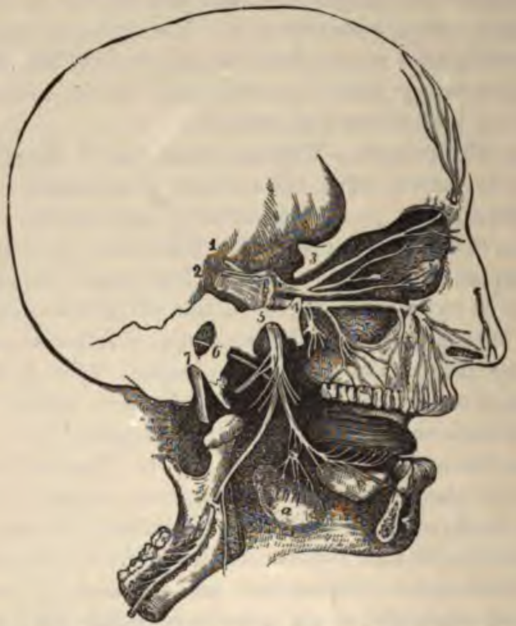


FIG. 346.—General plan of the branches of the fifth pair. 1-3.—1, lesser root of the fifth pair; 2, greater root passing forward into the Gasserian ganglion; 3, placed on the bone above the ophthalmic nerve, which is seen dividing into the supra-orbital, lachrymal, and nasal branches, the latter connected with the ophthalmic ganglion; 4, placed on the bone close to the foramen rotundum, marks the superior maxillary division, which is connected below with the spheno-palatine ganglion, and passes forward to the infra-orbital foramen; 5, placed on the bone over the foramen ovale, marks the inferior maxillary nerve, giving off the anterior auricular and muscular branches, and continued by the inferior dental to the lower jaw, and by the gustatory to the tongue; *a*, the submaxillary gland, the submaxillary ganglion placed above it in connection with the gustatory nerve; 6, the chorda tympani; 7, the facial nerve issuing from the stylo-mastoid foramen. (Charles Bell.)

Other Functions.—In relation to *muscular movements,* the branches of the greater or ganglionic portion of the fifth nerve exercise a manifold influence on the movements of the muscles of the head and face, and other parts in which they are distributed. They do so, in the first place (*a*), by providing the muscles themselves with that sensibility without which the mind, being unconscious of their position and state, cannot voluntarily exercise them. It is, probably, for conferring this sensibility on the muscles, that the branches of the fifth nerve communicate so frequently with those of the facial and hypoglossal, and the nerves of the muscles of the eye; and it is because of the loss of this sensibility that when the fifth nerve is divided, animals are always slow and awkward in the movement of the muscles of the face and head, or hold them still, or guide their movements by the sight of the objects toward which they wish to move.

Again, the fifth nerve has an indirect influence on the muscular movements by (*b*) conveying sensations of the state and position of the skin and other parts: which the mind perceiving, is enabled to determine appropriate acts. Thus, when the fifth nerve or its infra-orbital branch is divided, the movements of the lips in feeding may cease, or be imperfect. Bell supposed that the motion of the upper lip in grasping food depended directly on the infra-orbital nerve; for he found that, after he had divided that nerve on both sides in an ass, it no longer seized the food with its lips, but merely pressed them against the ground, and used the tongue for the prehension of the food. Mayo corrected this error. He found, indeed, that after the infra-orbital nerve had been divided, the animal did not seize its food with the lip, and could not use it well during mastication, but that it could open the lips. He, therefore, justly attributed the phenomena in Bell's experiments to the loss of sensation in the lips; the animal not being able to feel the food, and, therefore, although it had the power to seize it, not knowing how or where to use that power.

The fifth nerve has also (*c*), an intimate connection with muscular movements through the many reflex acts of muscles of which it is the necessary excitant. Hence, when it is divided and can no longer convey impressions to the nervous centres to be thence reflected, the irritation of the conjunctiva produces no closure of the eye, the mechanical irritation of the nose excites no sneezing.

Through its ciliary branches and the branch which forms the long root of the ciliary or ophthalmic ganglion, it exercises also (*d*), some influence on the movements of the iris.

When the trunk of the ophthalmic portion is divided, the pupil becomes, according to Valentin, contracted in men and rabbits, and dilated in cats and dogs; but in all cases, becomes immovable even under all the varieties of the stimulus of light. How the fifth nerve thus affects the iris is unexplained; the same effects are produced by destruction of the superior cervical ganglion of the sympathetic, so that, possibly, they are due to the injury of those filaments of the sympathetic which, after joining the trunk of the fifth, at and beyond the Gasserian ganglion, proceed with the branches of its ophthalmic division to the iris; or, as R. Hall ingeniously suggests, the influence of the fifth nerve on the movements of the iris may be ascribed to the affection of vision in consequence of the disturbed circulation or nutrition in the retina, when the normal influence of the fifth nerve and ciliary ganglion is disturbed. In such disturbance, increased circulation making the retina more irritable might induce extreme contraction of the iris; or under moderate stimulus of light, producing partial blindness, might induce dilatation: but it does not appear why, if this be the true explanation, the iris should in either case be immovable and unaffected by the various degrees of light.

Trophic influence.—Furthermore, the morbid effects which division of the fifth nerve produces in the organs of special sense, make it probable that, in the normal state, the fifth nerve exercises some *trophic* influence on all these organs; although, in part, the effect of the section of the nerve is only indirectly destructive by abolishing sensation, and therefore the natural safeguard which leads to the protection of parts from external injury. Thus, after such division, within a period varying from twenty-four hours to a week, the cornea begins to be opaque; then it grows completely white; a low destructive inflammatory process ensues in the conjunctiva, sclerotica, and interior parts of the eye; and within one or a few weeks, the whole eye mây be quite disorganized, and the cornea may slough or be penetrated by a large ulcer. The sense of smell (and not merely that of mechanical irritation of the nose), may be at the same time lost or gravely impaired; so may the hearing, and commonly, whenever the fifth nerve is paralyzed, the tongue loses the sense of taste in its anterior and lateral parts, *i.e.*, in the portion in which the lingual or gustatory branch of the inferior maxillary division of the fifth is distributed.

In relation to Taste.—The loss of the sense of taste is no doubt due (*a*) to the lingual branch of the fifth nerve being a nerve of special sense: partly, also, it is due (*b*), to the fact that this branch supplies, in the anterior and lateral parts of the tongue, a necessary condition for the proper nutrition of that part; while (*c*), it forms also one chief link in the nervous circle for reflex action, in the secretion of saliva (p. 231, Vol. I.). But, deferring this question until the glosso-pharyngeal nerve is to be considered, it may be observed that in some brief time after complete paralysis or division of the fifth nerve, the power of all the organs of the special senses may be lost; they may lose not merely their sensibility to common impressions, for which they all depend directly on the fifth nerve, but also their sensbility to their several peculiar impressions for the reception and conduction of which they are purposely constructed and supplied with special nerves besides the fifth. The facts observed in these cases can, perhaps, be only explained by the influence which the fifth nerve exercises on the nutritive processes in the organs of the special senses. It is not unreasonable to believe, that, in paralysis of the fifth nerve, their tissues may be the seats of such changes as are seen in the laxity, the vascular congestion, œdema, and other affections of the skin of the face and other tegumentary parts which also accompany the paralysis; and that these changes, which may appear unimportant when they affect external parts, are sufficient to destroy that refinement of structure by which the organs of the special senses are adapted to their functions.

That complete paralysis of the fifth nerve may be unaccompanied, at least for a considerable period, by injury to the organs of special sense, with the exception of that portion of the tongue which is supplied by its gustatory branch, is well illustrated by a valuable case recorded by Althaus.

According to Magendie and Longet, destruction of the eye ensues more quickly after division of the trunk of the fifth beyond the Gasserian ganglion, or after division of the ophthalmic branch, than after division of the roots of the fifth between the brain and the ganglion. Hence it would appear as if the influence on nutrition were conveyed in part through the filaments of the sympathetic, which joins the branches of the fifth nerve at and beyond the Gasserian ganglion.

The existence of ganglia of the sympathetic in connection with all the principal divisions of the fifth nerve where it gives off those branches which supply the organs of special sense—for example, the connection of the ophthalmic ganglion with the ophthalmic nerve at the origin of the ciliary nerves; of the spheno-palatine ganglion with the superior maxillary division, where it gives its branches to the nose and the palate; of the otic ganglion with the inferior maxillary near the giving off of filaments to the internal ear; and of the sub-maxillary ganglion with the lingual branch of the fifth—all these connections suggest that a peculiar and probably conjoint influence of the sympathetic and fifth nerves is exercised in the nutrition of the organs of the special senses; and the results of experiment and disease confirm this, by showing that the nutrition of the organs may be impaired in consequence of impairment of the power of either of the nerves.

In relation to Sight.—A possible but doubtful connection between the fifth nerve and the sense of sight, has been thought to be shown in cases in which blows or other injuries implicating the frontal nerve as it passes over the brow, are followed by total blindness in the corresponding eye. In some cases the blindness occurs at once, probably from concussion of the retina; but in others it is very slowly progressive, as if from defective nutrition of the retina, and may be accompanied with inflammatory disorganization, like that previously referred to (p. 141, Vol. II.). The connection of the fifth nerve with the result must, however, be considered very doubtful.

SIXTH NERVE.

Functions.—The sixth nerve, *Nervus abducens* or *ocularis externus*, is also, like the fourth, exclusively motor, and supplies only the rectus externus muscle.

The rectus externus is convulsed, and the eye is turned outward, when the sixth nerve is irritated; and the muscle is paralyzed when the nerve is divided. In all such cases of paralysis, the eye squints inward, and cannot be moved outward.

In its course through the cavernous sinus, the sixth nerve forms larger communications with the sympathetic nerve than any other nerve within the cavity of the skull does. But the import of these communications with the sympathetic, and the subsequent distribution of its filaments after joining the sixth nerve, are quite unknown.

SEVENTH OR FACIAL NERVE.

Functions.—The facial or *portio dura* of the seventh pair of nerves, is the motor nerve of all the muscles of the face, including the platysma, but not including any of the muscles of mastication already enumerated (p. 225, Vol. I.); it supplies, also, the parotid gland, and through the connection of its trunk with the Vidian nerve, by the petrosal nerves, some of the muscles of the soft palate, probably the levator palati and azygos uvulæ; by its tympanic branches it supplies the stapedius and laxator tympani, and, through the otic ganglion, the tensor tympani; through the *chorda tympani* it sends branches to the submaxillary gland and to the lingualis and some other muscular fibres of the tongue; and by branches given off before it comes upon the face, it supplies the muscles of the external ear, the posterior part of the digastricus, and the stylo-hyoideus.

Besides its *motor* influence, the facial is also, by means of the fibres which are supplied to the submaxillary and parotid glands, a *secretory* nerve. For, through the last-named branches, impressions may be conveyed which excite increased secretion of saliva (p. 232, Vol. I.).

Symptoms of Paralysis of Facial Nerve.—When the facial nerve is divided, or in any other way paralyzed, the loss of power in the muscles which it supplies, while proving the nature and extent of its functions, displays also the necessity of its perfection for the perfect exercise of all the organs of the special senses. Thus, in paralysis of the facial nerve, the orbicularis palpebrarum being powerless, the eye remains open through the unbalanced action of the levator palpebræ; and the conjunctiva, thus continually exposed to the air and the contact of dust, is liable to repeated inflammation, which may end in thickening and opacity of both its own tissue and that of the cornea. These changes, however, ensue much more slowly than those which follow paralysis of the fifth nerve, and never bear the same destructive character.

The sense of hearing, also, is impaired in many cases of paralysis of the facial nerve; not only in such as are instances of simultaneous disease in the auditory nerves, but in such as may be explained by the loss of power in the muscles of the internal ear. The sense of smell is commonly at the same time impaired through the inability to draw air briskly toward the upper part of the nasal cavities in which part alone the olfactory nerve is distributed; because, to draw the air perfectly in this direction, the action of the dilators and compressors of the nostrils should be perfect.

Lastly, the sense of taste is impaired or may be wholly lost in paralysis of the facial nerve, provided the source of the paralysis be in some part of the nerve between its origin and the giving off of the chorda tympani. This result, which has been observed in many instances of disease of the facial nerve in man, appears explicable by the influence which, through the chorda tympani, it exercises on the movements of the lingualis and the adjacent muscular fibres of the tongue; and on the process of secretion of saliva.

Together with these effects of paralysis of the facial nerve, the muscles of the face being all powerless, the countenance acquires on the paralyzed side a characteristic, vacant look, from the absence of all expression: the angle of the mouth is lower, and the paralyzed half of the mouth looks longer than that on the other side; the eye has an unmeaning stare. All these peculiarities increase, the longer the paralysis lasts; and their appearance is exaggerated when at any time the muscles of the opposite side of the face are made active in any expression, or in any of their ordinary functions. In an attempt to blow or whistle, one side of the mouth and cheek acts properly, but the other side is motionless, or flaps loosely at the impulse of the expired air; so in trying to suck, one side only of the mouth acts; in feeding, the lips and cheek are powerless, and food lodges between the cheek and gum.

GLOSSO-PHARYNGEAL NERVE.

The glosso-pharyngeal nerves (16, Fig. 347), in the enumeration of the cerebral nerves by numbers according to the position in which they leave the cranium, are considered as divisions of the *eighth pair of nerves*, in which term are included with them the pneumogastric and accessory nerves. But the union of the nerves under one term is inconvenient, although in some parts the glosso-pharyngeal and pneumogastric are so combined in their distribution that it is impossible to separate them in either their anatomy or physiology.

Distribution.—The glosso-pharyngeal nerve gives filaments through its tympanic branch (Jacobson's nerve,) to the fenestra ovalis, and fenestra rotunda, and the Eustachian tube; also, to the carotid plexus, and, through the petrosal nerve, to the spheno-palatine ganglion. After communicating, either within or without the cranium, with the pneumogastric, and soon after it leaves the cranium, with the sympathetic, digastric branch of the facial, and the accessory nerve, the glosso-pharyngeal nerve parts into the two principal divisions indicated by its name, and supplies the mucous membrane of the posterior and lateral walls of the upper part of the pharynx, the Eustachian tube, the arches of the palate, the tonsils and their mucous membrane, and the tongue as far forward as the foramen cæcum in the middle line, and to near the tip at the sides and inferior part.

Functions.—The glosso-pharyngeal nerve contains some motor fibres, together with those of common sensation and the sense of taste. 1. The muscles which receive filaments from the glosso-pharyngeal are the stylo-pharyngei, palato-glossi, and constrictors of the pharynx.

Besides being (2) a nerve of common sensation in the parts which it supplies, and a centripetal nerve through which impressions are conveyed to be reflected to the adjacent muscles, the glosso-pharyngeal is also a nerve of special sensation; being the nerve of taste, in all the parts of the tongue and palate to which it is distributed. After many discussions, the question, Which is the nerve of taste?—the lingual branch of the fifth, or the glosso-pharyngeal?—may be most probably answered by stating that they are both nerves of this special function. For very numerous experiments and cases have shown that when the trunk of the fifth nerve or its lingual branch is paralyzed or divided, the sense of taste is completely lost in the superior surface of the anterior and lateral parts of the tongue. The loss is instantaneous after division of the nerve; and, therefore, cannot be ascribed to the defective nutrition of the part, though to this, perhaps, may be ascribed the more complete and general loss of the sense of taste when the whole of the fifth nerve has been paralyzed.

But, on the other hand, while the loss of taste in the part of the tongue to which the lingual branch of the fifth nerve is distributed proves that to be a gustatory nerve, the fact that the sense of taste is at the same time retained in the posterior and postero-lateral parts of the tongue, and in the soft palate and its anterior arch, to which (and to some parts of which exclusively) the glosso-pharyngeal is distributed, proves that this also must be a nerve of taste.

PNEUMOGASTRIC OR VAGUS NERVE.

Distribution.—The *pneumogastric nerve, nervus vagus,* or *par vagum* (1, Fig. 347), has, of all the cranial and spinal nerves, the most various distribution, and influences the most various functions, either through its own filaments, or those which, derived from other nerves, are mingled in its branches. The parts supplied by the branches of the vagus nerve are as follows: by its pharyngeal branches, which enter the pharyngeal plexus, a large portion of the mucous membrane, and, probably, all the muscles of the Pharynx; by the superior laryngeal nerve, the mucous membrane of the under surface of the Epiglottis, the Glottis, and the greater part of the Larynx, and the crico-thyroid muscle; by the inferior laryngeal nerve, the mucous membrane and muscular fibres of the Trachea, the lower part of the pharynx and larynx, and all the muscles of the larynx except the crico-thyroid; by œsophageal branches, the mucous membrane and muscular coats of the Œsophagus. Moreover, the branches of the vagus form a large portion of the supply of nerves to the Heart and the great Arteries through the cardiac nerves, derived from both the trunk and the recurrent nerve; to the Lungs, through both the anterior and

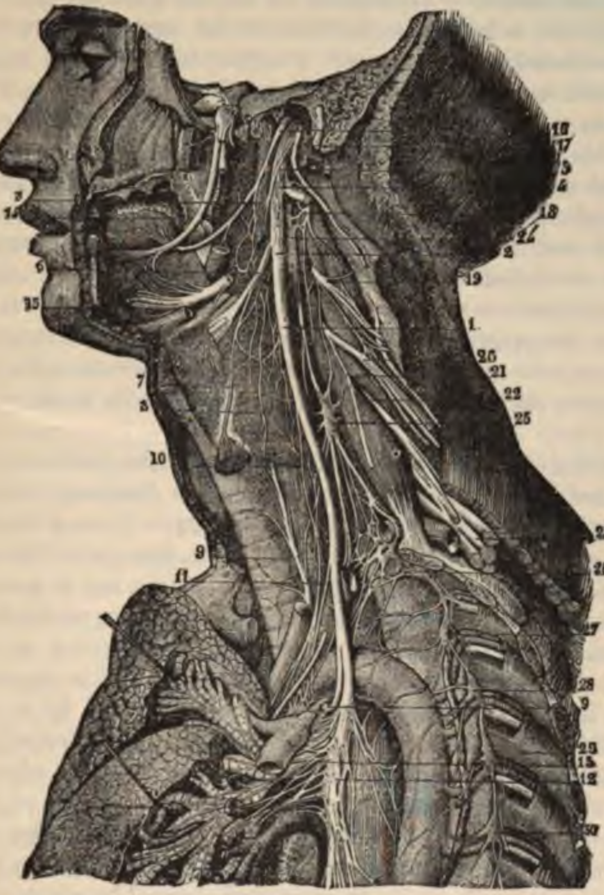


FIG. 347.—View of the nerves of the eighth pair, their distribution and connections on the left side. 2-5.—1, pneumogastric nerve in the neck; 2, ganglion of its trunk; 3, its union with the spinal accessory; 4, its union with the hypoglossal; 5, pharyngeal branch; 6, superior laryngeal nerve; 7, external laryngeal; 8, laryngeal plexus; 9, inferior or recurrent laryngeal; 10, superior cardiac branch; 11, middle cardiac; 12, plexiform part of the nerve in the thorax; 13, posterior pulmonary plexus; 14, lingual or gustatory nerve of the inferior maxillary; 15, hypoglossal, passing into the muscles of the tongue, giving its thyroid-hyoid branch, and uniting with twigs of the lingual; 16, glosso-pharyngeal nerve; 17, spinal accessory nerve, uniting by its inner branch with the pneumogastric, and by its outer, passing into the sterno-mastoid muscle; 18, second cervical nerve; 19, third; 20, fourth; 21, origin of the phrenic nerve, 22, 23, fifth, sixth, seventh, and eighth cervical nerves, forming with the first dorsal the brachial plexus; 24, superior cervical ganglion of the sympathetic; 25, middle cervical ganglion; 26, inferior cervical ganglion united with the first dorsal ganglion; 27, 28, 39, 30, second, third, fourth, and fifth dorsal ganglia. (From Sappey after Hirschfeld and Leveillé.)

the posterior pulmonary plexuses; and to the Stomach, by its terminal branches passing over the walls of that organ; while branches are also distributed to the Liver and to the Spleen.

Communications.—Throughout its whole course, the vagus contains both sensory and motor fibres; but after it has emerged from the skull, and in some instances even sooner, it enters into so many anastomoses that it is hard to say whether the filaments it contains are, from their origin, its own, or whether they are derived from other nerves combining with it. This is particularly the case with the filaments of the sympathetic nerve, which are abundantly added to nearly all its branches. The likeness to the sympathetic which it thus acquires is further increased by its containing many filaments derived, not from the brain, but from its own petrosal ganglia, in which filaments originate, in the same manner as in the ganglia of the sympathetic, so abundantly that the trunk of the nerve is visibly larger below the ganglia than above them (Bidder and Volkmann). Next to the sympathetic nerve, that which most communicates with the vagus is the accessory nerve, whose internal branch joins its trunk, and is lost in it.

Functions.—The most probable account of the particular functions which the branches of the pneumogastric nerve discharge in the several parts to which they are distributed, may be drawn from John Reid's experiments on dogs. They show that,—1. The *pharyngeal* branch is the principal *motor* nerve of the pharynx and soft palate, and is most probably wholly motor; the chief part of its motor fibres being derived from the internal branch of the accessory nerve. 2. The *inferior* or *recurrent laryngeal* nerve is the motor nerve of the larynx. 3. The *superior laryngeal* nerve is chiefly sensory: the only muscle supplied by it being the crico-thyroid. 4. The motions of the *œsophagus*, the stomach and part of the small intestines, are dependent on motor fibres of the vagus, and are probably excited by impressions made upon sensitive fibres of the same. 5. The *cardiac* branches communicate, from the centre in the medullary channel, impulses (inhibitory) regulating the action of the heart. 6. The *pulmonary* branches form the principal channel by which the sensory impressions on the mucous surface of the trachea, bronchi and lungs that influence respiration are transmitted to the medulla oblongata; and some fibres also supply motor influence to the muscular portions of the fibres of the trachea and bronchi. 7. Branches to the stomach and intestines not only convey motor but also *vaso-motor* impulses to those organs. 8. The action of the so-called *depressor* branch (p. 154, Vol. I.) in *inhibiting the action of the vaso-motor centre* has already been treated of, as has also the influence of the vagus in stimulating the secretion of the salivary glands, as in the nausea which precedes vomiting (p. 232, Vol. I.). To summarize, therefore, the many functions of this nerve, it may be said that it supplies *motor* influence to the pharynx and œsophagus, to stomach and small intestine, and to the larynx, trachea, bronchi and lung; *sensory* and in part *vaso-motor* influence to the same regions; *inhibitory* influence to the heart; *inhibitory* afferent impulses to the vaso-motor centre; *excito-secretory* to the salivary glands; *excito-motor* in coughing, vomiting, etc.

Effects of Section.—Division of both vagi, or of both their recurrent branches, is often very quickly fatal in young animals; but in old animals the division of the recurrent nerve is not generally fatal, and that of both the vagi is not always fatal, and, when it is so, death ensues slowly. This difference is, probably, because the yielding of the cartilages of the larynx in young animals permits the glottis to be closed by the atmospheric pressure in inspiration, and they are thus quickly suffocated unless tracheotomy be performed. In old animals, the rigidity and prominence of the arytenoid cartilages prevent the glottis from being completely closed by the atmospheric pressure; even when all the muscles are paralyzed, a portion at its posterior part remains open, and through this the animal continues to breathe.

In the case of slower death, after division of both the vagi, the lungs are commonly found gorged with blood, œdematous, or nearly solid, with a kind of low pneumonia, and with their bronchial tubes full of frothy bloody fluid and mucus, changes to which, in general, the death may be proximately ascribed. These changes are due, perhaps in part, to the influence which the nerves exercise on the movements of the air-cells and bronchi; yet, since they are not always produced in one lung when its nerve is divided, they cannot be ascribed wholly to the suspension of organic nervous influence. Rather, they may be ascribed to the hindrance to the passage of blood through the lungs, in consequence of the diminished supply of air and the excess of carbonic acid in the air-cells and in the pulmonary capillaries; in part, perhaps, to paralysis of the blood-vessels, leading to congestion; and in part, also, they appear due to the passage of food and of the various secretions of the mouth and fauces through the glottis, which, being deprived of its sensibility, is no longer stimulated or closed in consequence of their contact.

References to other functions of Vagi.—Regarding the influence of the vagus, see also Heart (p. 126, Vol. I.), Arteries (p. 154, Vol. I.), Salivary Gland (p. 232, Vol. I.), Glottis and Larynx (p. 202, Vol. I.), Trachea and Bronchi (p. 183, Vol. I.), Lungs (p. 202, Vol. I.), Pharynx and Œsophagus (p. 239, Vol. I.), Stomach (p. 252, Vol. I.).

SPINAL ACCESSORY NERVE.

The principal branch of the accessory nerve, its external branch, supplies the sterno-mastoid and trapezius muscles; and, though pain is produced by irritating it, is composed almost exclusively of motor fibres. It is very probable that the accessory nerve gives some motor filaments to the vagus.

For, among the experiments made on this point, many have shown that when the accessory nerve is irritated within the skull, convulsive movements ensue in some of the muscles of the larynx; all of which, as already stated, are supplied, apparently, by branches of the vagus; and (which is a very significant fact) Vrolik states that in the chimpanzee the internal branch of the accessory does not join the vagus at all, but goes direct to the larynx.

Among the roots of the accessory nerve, the lower, arising from the spinal cord, appear to be composed exclusively of motor fibres, and to be destined entirely to the trapezius and sterno-mastoid muscles; the upper fibres, arising from the medulla oblongata, contain many sensory as well as motor fibres.

HYPOGLOSSAL NERVE.

Distribution.—The hypoglossal or ninth nerve, or *moto linguæ*, has a peculiar relation to the muscles connected with the hyoid bone, including those of the tongue. It supplies through its descending branch (*descendens noni*), the sterno-hyoid, sterno-thyroid, and omo-hyoid; through a special branch of the thyro-hyoid, and through its lingual branches the genio-hyoid, stylo-glossus, hyo-glossus, and genio-hyo-glossus, and linguales. It contributes, also, to the supply of the submaxillary gland.

Functions.—The function of the hypoglossal is exclusively motor, except in so far as its descending branch may receive a few sensory filaments from the first cervical nerve. As a motor nerve, its influence on all the muscles enumerated above is shown by their convulsions when it is irritated, and by their loss of power when it is paralyzed. The effects of the paralysis of one hypoglossal nerve are, however, not very striking in the tongue. Often, in cases of hemiplegia involving the functions of the hypoglossal nerve, it is not possible to observe any deviation in the direction of the protruded tongue; probably because the tongue is so compact and firm that the muscles on either side, their insertion being nearly parallel to the median line, can push it straight forward or turn it for some distance toward either side.

SPINAL NERVES

Functions.—Little need be added to what has been already said of these nerves (pp. 93 to 97, Vol. II.). The anterior roots of the spinal nerves are formed exclusively of motor fibres; the posterior roots exclusively of sensory fibres. Beyond the ganglia, all the spinal nerves are mixed nerves, and contain as well sympathetic filaments.

THE SYMPATHETIC NERVE.

The general differences between the fibres of the cerebro-spinal and sympathetic nerves have been already stated (pp. 71, 72, Vol. II.), but the different modes of action of the two systems cannot be referred to the different structure of their fibres. It is probable, however, that the laws of conduction by the fibres are in both systems the same, and that the differences manifest in the modes of action of the systems are due to the multiplication and separation of the nervous centres of the sympathetic: ganglia, or nerve-centres, being placed in connection with the fibres of the sympathetic in nearly all parts of their course.

Distribution.—1. Fibres are distributed to all plain or unstriped muscular fibres, as those of the blood-vessels (vaso-motor nerves), of the muscular coats of the intestines and other hollow viscera, of gland-ducts, of the iris and ciliary muscle in the eye, and elsewhere.

The vaso-motor fibres come originally from the *vaso-motor centre* in the medulla oblongata; and, issuing from the spinal cord, communicate with the præ-vertebral chain of ganglia, and are thence, as branches from these, distributed to the Blood-vessels. 2. Fibres (accelerating) are distributed to the Heart. 3. Secretory fibres (in addition to vaso-motor) are distributed to the salivary, and presumably to other secreting glands. 4. Intercentral or inter-ganglionic fibres. 5. *Centripetal* fibres proceeding to the vaso-motor centre in the medulla; to the various sympathetic ganglia; and probably to all cerebro-spinal nerve-centres. The *peripheral* distribution of these centripetal fibres is, without doubt, chiefly in the parts or organs to which the *centrifugal* fibres of the same system are mainly distributed. But they are also present in all those other parts of the body which belong more especially to the Cerebro-spinal system.

Structure.—The sympathetic ganglia all contain—(1), nerve-fibres traversing them; (2), nerve-fibres originating in them; (3), nerve or ganglion corpuscles, giving origin to these fibres; and (4), other corpuscles that appear free. In the sympathetic ganglia of the frog, ganglion-cells of a very complicated structure have been described by Beale and subsequently by Arnold. The cells are enclosed each in a nucleated capsule: they are pyriform in shape, and from the pointed end two fibres are given off, which gradually acquire the characters of nerve-fibres: one of them is straight, and the other (which sometimes arises from the cell by two roots) is spirally coiled around it.

In the trunk, and thence proceeding branches of the sympathetic, there appear to be always—(1), fibres which arise in its own ganglia; (2), fibres derived from the ganglia of the cerebral and spinal nerves; (3), fibres derived from the brain and spinal cord and transmitted through the

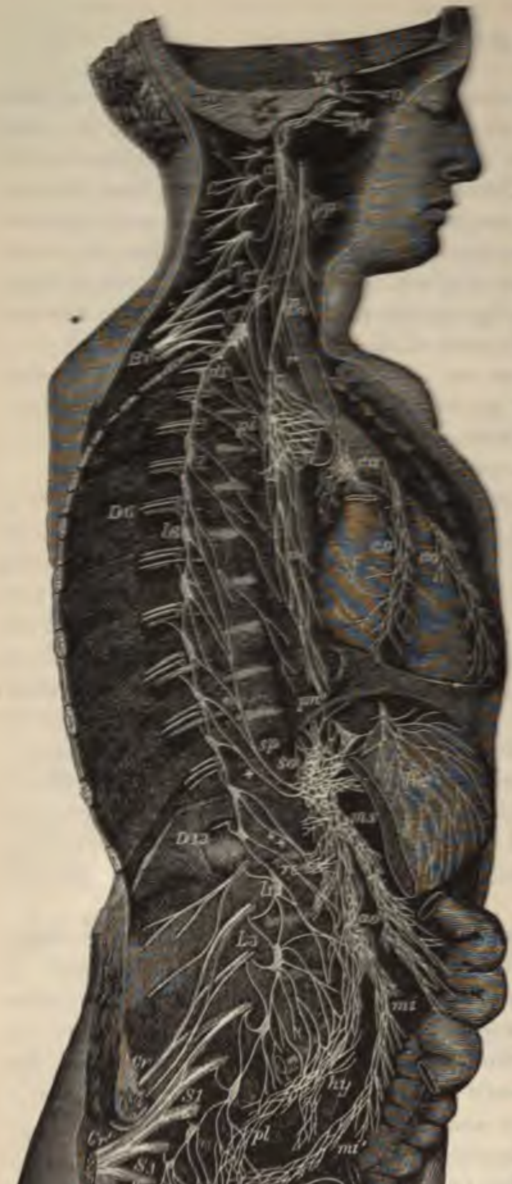


FIG. 348.

roots of their nerves. The spinal cord, indeed, appears to be a large source of the fibres of the sympathetic nerve.

Through the communicating branches between the spinal nerves and the præ-vertebral sympathetic ganglia, which have been generally called roots or origins of the sympathetic nerve, an interchange is effected between all the spinal nerves and the sympathetic trunks; all the ganglia, also, which are seated on the cerebral nerves, have roots (as they are called) through which filaments of the cerebral nerves are added to their own. So that, probably, all sympathetic nerves contain some intermingled cerebral or spinal nerve-fibres; and all cerebral and spinal nerves, some filaments derived from the sympathetic system or from ganglia. But the proportions in which these filaments are mingled are not uniform. The nerves which arise from the brain and spinal cord retain throughout their course and distribution a preponderance of *cerebro-spinal* fibres, while the nerves immediately arising from the so-called sympathetic ganglia probably contain a majority of *sympathetic* fibres. But inasmuch as there is no certainty that in structure the branches of cerebral or spinal nerves differ always from those of the sympathetic system, it is impossible in the present state of our knowledge to be sure of the source of fibres which from their structure might lead the observer to believe that they arose from the brain or spinal cord on the one hand, or from the sympathetic ganglia on the other. In other words, although the large white medullated fibres are especially characteristic of cerebro-spinal nerves, and the pale or non-medullated fibres of a sympathetic nerve, in which they largely preponderate, there is no certainty to be obtained in a doubtful case, of whether the nerve-fibre is derived from one or the other, from mere examination of its structure. It may be derived from either source.

Functions.—It may be stated generally that the sympathetic nerve-fibres are simple conductors of impressions, as are those of the Cerebro-spinal system; and that the ganglionic centres have (each in its appropriate sphere) the like powers both of *conducting, transferring, reflecting,* and possibly of *augmenting* or of *inhibiting* impressions made on them.

The power possessed by the sympathetic ganglia of conducting impressions is sufficiently proved in disease, as when any of the viscera, usually unfelt, give rise to sensations of pain, or when a part not commonly subject to mental influence is excited or retarded in its actions by the various conditions of the mind; for in all these cases impressions must be conducted to and fro through the whole distance between the part and the spinal cord and brain. So, also, in experiments, now more than

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FIG. 348.—Diagrammatic view of the Sympathetic cord of the right side, showing its connections with the principal cerebro-spinal nerves and the main præaortic plexuses. 1-4. (From Quain's Anatomy.)

Cerebro-spinal nerves.—VI, a portion of the sixth cranial as it passes through the cavernous sinus, receiving two twigs from the carotid plexus of the sympathetic nerve; O, ophthalmic ganglion connected by a twig with the carotid plexus; M, connection of the spheno-palatine ganglion by the Vidian nerve with the carotid plexus; C, cervical plexus; Br, brachial plexus; D 6, sixth intercostal nerve; D 12, twelfth; L 3, third lumbar nerve; S 1, first sacral nerve; S 3, third; S 5, fifth; Cr, anterior crural nerve; Cr′, great sciatic; *pn*, pneumogastric nerve in the lower part of the neck; *r*, recurrent nerve winding round the subclavian artery.

Sympathetic Cord.—*c*, superior cervical ganglion; *c′*, second or middle; *c″*, inferior: from each of these ganglia cardiac nerves (all deep on this side) are seen descending to the cardiac plexus; *d* 1, placed immediately below the first dorsal sympathetic ganglion; *d* 6, is opposite the sixth; *l* 1, first lumbar ganglion; *c g*, the terminal or coccygeal ganglion.

Præaortic and Visceral Plexuses.—*p p*, pharyngeal, and, lower down, laryngeal plexus; *pl*, posterior pulmonary plexus spreading from the vagus on the back of the right bronchus; *c a*, on the aorta, the cardiac plexus, toward which, in addition to the cardiac nerves from the three cervical sympathetic ganglia, other branches are seen descending from the vagus and recurrent nerves; *co*, right or posterior, and *co′*, left or anterior coronary plexus; *o*, œsophageal plexus in long meshes on the gullet; *sp*, great splanchnic nerve formed by branches from the fifth, sixth, seventh, eighth, and ninth dorsal ganglia; +, small splanchnic from the ninth and tenth; + +, smallest or third splanchnic from the eleventh: the first and second of these are shown joining the solar plexus, *s o;* the third descending to the renal plexus, *r e;* connecting branches between the solar plexus and the vagi are also represented; *pn′*, above the place where the right vagus passes to the lower or posterior surface of the stomach; *pn″*, the left distributed on the anterior or upper surface of the cardiac portion of the organ: from the solar plexus large branches are seen surrounding the arteries of the cœliac axis, and descending to *m s*, the superior mesenteric plexus; opposite to this is an indication of the supra-renal plexus; below *r e* (the renal plexus), the spermatic plexus is also indicated; *a o*, on the front of the aorta, marks the aortic plexus, formed by nerves descending from the solar and superior mesenteric plexuses and from the lumbar ganglia; *mi*, the inferior mesenteric plexus surrounding the corresponding artery; *hy*, hypogastric plexus placed between the common iliac vessels, connected above with the aortic plexus, receiving nerves from the lower lumbar ganglia, and dividing below into the right and left pelvic or inferior hypogastric plexuses; *pl*, the right pelvic plexus; from this the nerves descending are joined by those from the plexus on the superior hemorrhoidal vessels, *mi′*, by sympathetic nerves from the sacral ganglia, and by numerous visceral nerves from the third and fourth sacral spinal nerves, and there are thus formed the rectal, vesical, and other plexuses, which ramify upon the viscera from behind forward and from below upward, as toward *ir*, and *v*, the rectum and bladder.

sufficiently numerous, irritations of the semilunar ganglia, the splanchnic nerves, the thoracic, hepatic, and other ganglia and nerves, have elicited expressions of pain, and have excited movements in the muscular organs supplied from the irritated part.

In the case of pain, or of movements affected by mental conditions, it may be supposed that the conduction of impressions is effected through the cerebro-spinal fibres which are mingled in all, or nearly all, parts of the sympathetic nerves. There are no means of deciding this; but if it be admitted that the conduction is effected through the cerebro-spinal nerve-fibres, then, whether or not they pass uninterruptedly between the brain or spinal cord and the part affected, it must be assumed that their mode of conduction is modified by the ganglia. For, if such cerebro-spinal fibres are conducted in the ordinary manner, the parts should be always sensible and liable to the influence of the will, and impressions should be conveyed to and fro instantaneously. But this is not the case; on the contrary, through the branches of the sympathetic nerve and its ganglia, none but intense impressions, or impressions exaggerated by the morbid excitability of the nerves or ganglia, can be conveyed.

Respecting the general action of the ganglia of the sympathetic nerve, in reflex or other actions, little need be said here, since they may be taken as examples by which to illustrate the common modes of action of all nerve-centres (see p. 83, Vol. II.). Indeed, complex as the sympathetic system, taken as a whole, is, it presents in each of its parts a simplicity not to be found in the cerebro-spinal system: for each ganglion with afferent and efferent nerves forms a simple nervous system, and might serve for the illustration of all the nervous actions with which the mind is unconnected.

The parts principally supplied with sympathetic nerves are usually capable of none but involuntary movements, and when the mind acts on them at all, it is only through the strong excitement or depressing influence of some passion, or through some voluntary movement with which the actions of the involuntary part are commonly associated. The heart, stomach, and intestines are examples of these statements; for the heart and stomach, though supplied in large measure from the pneumogastric nerves, yet probably derive through them few filaments except such as have arisen from their ganglia, and are therefore of the nature of sympathetic fibres.

The parts which are supplied with motor power by the sympathetic nerve continue to move, though more feebly than before, when they are separated from their natural connections with the rest of the sympathetic system, and wholly removed from the body. Thus, the heart, after it is taken from the body, continues to beat in Mammalia for one or two minutes, in reptiles and Amphibia for hours; and the peristaltic motions of the intestine continue under the same circumstances. Hence the motions of the parts supplied with nerves from the sympathetic are shown to be, in a measure, independent of the brain and spinal cord; this independent maintenance of their action being, without doubt, due to the fact that they contain, in their own substance, the apparatus of ganglia and nerve-fibres by which their motions are immediately governed.

It seems to be a general rule, at least in animals that have both cerebro-spinal and sympathetic nerves much developed, that the involuntary movements excited by stimuli conveyed through ganglia are orderly and like natural movements, while those excited through nerves without ganglia are convulsive and disorderly; and the probability is that, in the natural state, it is through the same ganglia that natural stimuli, impressing centripetal nerves, are reflected through centrifugal nerves to the involuntary muscles. As the muscles of respiration are maintained in uniform rhythmic action chiefly by the reflecting and combining power of the medulla oblongata, so are those of the heart, stomach, and intestines, by their several ganglia. And as with the ganglia of the sympathetic and their nerves, so with the medulla oblongata and its nerves distributed to the respiratory muscles,—if these nerves of the medulla oblongata itself be directly stimulated, the movements that follow are convulsive and disorderly; but if the medulla be stimulated through a centripetal nerve, as when cold is applied to the skin, then the impressions are reflected so as to produce movements which, though they may be very quick and almost convulsive, are yet combined in the plan of the proper respiratory acts.

Among the ganglia of the sympathetic nerves to which this co-ordination of movements is to be ascribed, must be reckoned, not those alone which are on the principal trunks and branches of the sympathetic external to any organ, but those also which lie in the very substance of the organs; such as those of the heart (p. 125, Vol. I.). Those also may be included which have been found in the mesentery close by the intestines, as well as in the muscular and sub-mucous tissue of the stomach and intestinal canal (pp. 244, 255, Vol. I.), and in other parts. The extension of discoveries of such ganglia will probably diminish yet further the number of instances in which the involuntary movements appear to be effected independently of nervous influence.

Respecting the influence of the sympathetic system on various physiological processes, see Heart (p. 127, Vol. I.), Arteries (p. 152, Vol. I.), Animal Heat (p. 316, Vol. I.), Salivary Glands (p. 233, Vol. I.), Stomach (p. 252, Vol. I.), Intestines (p. 255, Vol. I.). These are parts which have been specially investigated. But they are not in any way exceptional. All physiological processes must, of necessity, either directly or through vaso-motor fibres, be under the influence of the Sympathetic system.

Influence of the Nervous System on Nutrition.—It has been held that the nervous system cannot be essential to a healthy course of nutrition, because in plants and the early embryo, and in the lowest animals, in which no nervous system is developed, nutrition goes on without it. But this is no proof that in animals which have a nervous system, nutrition may be independent of it; rather, it may be assumed, that in ascending development, as one system after another is added or increased, so the highest (and, highest of all, the nervous system) will always be inserted and blended in a more and more intimate relation with all the rest; according to the general law, that the interdependence of parts augments with their development.

The reasonableness of this assumption is proved by many facts showing the influence of the nervous system on nutrition, and by the most striking of these facts being observed in the higher animals, and especially in man. The influence of the mind in the production, aggravation, and cure of organic diseases is matter of daily observation, and a sufficient proof of influence exercised on nutrition through the nervous system.

Independently of mental influence, injuries either to portions of the nervous centres, or to individual nerves, are frequently followed by defective nutrition of the parts supplied by the injured nerves, or deriving their nervous influence from the damaged portions of the nervous centres. Thus, lesions of the spinal cord are sometimes followed by mortification of portions of the paralyzed parts; and this may take place very quickly, as in a case in which the ankle sloughed within twenty-four hours after an injury of the spine. After such lesions also, the repair of injuries in the paralyzed parts may take place less completely than in others; so, in a case in which paraplegia was produced by fracture of the lumbar vertebræ, and, in the same accident, the humerus and tibia were fractured. The former in due time united: the latter did not. The same fact was illustrated by some experiments, in which having, in salamanders, cut off the end of the tail, and then thrust a thin wire some distance up the spinal canal, so as to destroy the cord, it was found that the end of the tail was reproduced more slowly than in other salamanders in whom the spinal cord was left uninjured above the point at which the tail was amputated. Illustrations of the same kind are furnished by the several cases in which division or destruction of the trunk of the trigeminal nerve has been followed by incomplete and morbid nutrition of the corresponding side of the face; ulceration of the cornea being often directly or indirectly one of the consequences of such imperfect nutrition. Part of the wasting and slow degeneration of tissue in paralyzed limbs is probably referable also to the withdrawal of nervous influence from them; though, perhaps, more is due to the want of use of the tissues.

Undue irritation of the trunks of nerves, as well as their division or destruction, is sometimes followed by defective or morbid nutrition. To this may be referred the cases in which ulceration of the parts supplied by the irritated nerves occurs frequently, and continues so long as the irritation lasts. Further evidence of the influence of the nervous system upon nutrition is furnished by those cases in which, from mental anguish, or in severe neuralgic headaches, the hair becomes grey very quickly, or even in a few hours.

So many and varied facts leave little doubt that the nervous system exercises an influence over nutrition as over other organic processes; and they cannot be easily explained by supposing that the changes in the nutritive processes are only due to the variations in the size of the blood-vessels supplying the affected parts, although this is, doubtless, one important element in producing the result.

The question remains, through what class of nerves is the influence exerted? When defective nutrition occurs in parts rendered inactive by injury of the motor nerve alone, as in the muscles and other tissues of a paralyzed face or limb, it may appear as if the atrophy were the direct consequence of the loss of power in the motor nerves; but it is more probable that the atrophy is the consequence of the want of exercise of the parts; for if the muscles be exercised by artificial irritation of their nerves their nutrition will be less defective. The defect of the nutritive process which ensues in the face and other parts, however, in consequence of destruction of the trigeminal nerve, cannot be referred to loss of influence of any motor nerves; for the motor-nerves of the face and eye, as well as the olfactory and optic, have no share in the defective nutrition which follows injury of the trigeminal nerve; and one or all of them may be destroyed without any direct disturbance of the nutrition of the parts they severally supply.

It must be concluded, therefore, that the influence which is exercised by nerves over the nutrition of parts to which they are distributed is to be referred, in part or altogether, either to the nerves of common sensation, or to the vaso-motor nerves, or, as it is by some supposed, to nerve fibres (*trophic* nerves), which preside specially over the nutrition of the tissues and organs to which they are supplied.

It is not at present possible to say whether the influence on nutrition is exercised through the cerebro-spinal or through the sympathetic nerves, which, in the parts on which the observation has been made, are generally combined in the same sheath. The truth perhaps is, that it may be exerted through either or both of these nerves. The defect of nutrition which ensues after lesion of the spinal cord alone, the sympathetic nerves being uninjured, and the general atrophy which sometimes occurs in consequence of diseases of the brain, seem to prove the influence of the cerebro-spinal system: while the observation that inflammation of the eye is a constant result of ligature of the sympathetic nerve in the neck, and many other observations of a similar kind, exhibit very well the influence of the latter nerve in nutrition.

CHAPTER XIX.

THE SENSES.

THROUGH the medium of the Nervous system the mind obtains a knowledge of the existence both of the various parts of the body, and of the external world. This knowledge is based upon *sensations* resulting from the stimulation of certain centres in the brain, by irritations conveyed to them by afferent (sensory) nerves. Under normal circumstances, the following structures are necessary for sensation: (*a*) A peripheral organ for the reception of the impression; (*b*) a nerve for conducting it; (*c*) a nerve-centre for feeling or perceiving it.

Classification of Sensations.—Sensations may be conveniently classed as (1) *common*, and (2) *special*.

(1.) *Common Sensations.*—Under this head fall all those general sensations which cannot be distinctly localized in any particular part of the body, such as Fatigue, Discomfort, Faintness, Satiety, together with Hunger and Thirst, in which, in addition to a general discomfort, there is in many persons a distinct sensation referred to the stomach or fauces. In this class must also be placed the various irritations of the mucous membrane of the bronchi, which give rise to coughing, and also the sensations derived from various viscera indicating the necessity of expelling their contents; *e.g.*, the desire to defæcate, to urinate, and, in the female, the sensations which precede the expulsion of the fœtus. We must also include such sensations as itching, creeping, tickling, tingling, burning, aching, etc., some of which come under the head of *pain:* they will be again referred to in describing the sense of *Touch*. It is impossible to draw a very clear line of demarcation between many of the common sensations above mentioned, and the sense of Touch, which forms the connecting link between the general and special sensations. Touch is, indeed, usually classed with the special senses, and will be considered in the same group with them; yet it differs from them in being common to many nerves, *e.g.*, all the sensory spinal nerves, the vagus, glosso-pharyngeal, and fifth cerebral nerves, and in its impressions being communicable through many organs. Among common sensations must also be ranked the *muscular sense*, which has been already alluded to. It is by means of this sense that we become aware of the condition of contraction or relaxation of the various muscles and groups of muscles, and thus obtain the information necessary for their adjustment to various purposes—standing, walking, grasping, etc. This muscular sensibility is shown in our power to estimate the differences between weights by the different muscular efforts necessary to raise them. Considerable delicacy may be attained by practice, and the difference between 19½ oz. in one hand and 20 oz. in the other is readily appreciated (Weber).

This sensibility with which the muscles are endowed must be carefully distinguished from the sense of *contact* and of *pressure*, of which the skin is the organ. When standing erect, we can feel the ground (contact), and further there is a sense of *pressure*, due to our feet being pressed against the ground by the weight of the body. Both these are derived from the skin of the sole of the foot. If now we raise the body on the toes, we are conscious (muscular sense) of a muscular effort made by the muscles of the calf, which overcomes a certain resistance.

(2.) *Special Sensations.*—Including the sense of touch, the special senses are five in number—Touch, Taste, Smell, Hearing, Sight.

Difference between Common and Special Sensations.—The most important distinction between common and special sensations is that by the former we are made aware of certain conditions of various parts of our bodies, while from the latter we gain our knowledge of the external world also. This difference will be clear if we compare the sensations of pain and touch, the former of which is a common, the latter a special sensation. "If we place the edge of a sharp knife on the skin, we feel the edge by means of our sense of touch; we perceive a sensation, and refer it to the object which has caused it. But as soon as we cut the skin with the knife, we feel pain, a feeling which we no longer refer to the cutting knife, but which we feel within ourselves, and which communicates to us the fact of a change of condition in our own body. By the sensation of pain we are neither able to recognize the object which caused it, nor its nature" (Weber).

General Characteristics: Seat.—In studying the phenomena of sensation, it is important clearly to understand that the *Sensorium*, or seat of sensation, is in the Brain, and not in the particular organ (eye, ear, etc.) through which the sensory impression is received. In common parlance we are said to *see* with the eye, *hear* with the ear, etc., but in reality these organs are only adapted to receive impressions which are conducted to the sensorium, through the optic and auditory nerves respectively, and there give rise to sensation.

Hence, if the optic nerve is severed (although the eye itself is perfectly uninjured), vision is no longer possible; since, although the image falls on the retina as before, the sensory impression can no longer be conveyed to the sensorium. When any given sensation is felt, all that we can with certainty affirm is that the sensorium in the brain is excited. The exciting cause may be (in the vast majority of cases is), some object of the external world (*objective sensation*); or the condition of the sensorium may be due to some excitement within the brain, in which case the sensation is termed *subjective*. The mind habitually refers sensations to external causes; and hence, whenever they are subjective (due to causes within the brain), we can hardly divest ourselves of the idea of an external cause, and an *illusion* is the result.

Illusions.—Numberless examples of such illusions might be quoted. As familiar cases may be mentioned, humming and buzzing in the ears caused by some irritation of the auditory nerve or centre, and even musical sounds and voices (sometimes termed auditory spectra); also so-called optical illusions: persons and other objects are described as being seen, although not present. Such illusions are most strikingly exemplified in cases of delirium tremens or other forms of delirium, in which cats, rats, creeping loathsome forms, etc., are described by the patient as seen with great vividness.

Causes of Illusions.—One uniform *internal* cause, which may act on all the nerves of the senses in the same manner, is the accumulation of blood in their capillary vessels, as in congestion and inflammation. This one cause excites in the retina, while the eyes are closed, the sensations of light and luminous flashes; in the auditory nerve, the sensation of humming and ringing sounds; in the olfactory nerve, the sense of odors; and in the nerves of feeling, the sensation of pain. In the same way, also, a narcotic substance, introduced into the blood, excites in the nerves of each sense peculiar symptoms: in the optic nerves, the appearance of luminous sparks before the eyes; in the auditory nerves, "tinnitus aurium"; and in the common sensory nerves, the sensation of creeping over the surface. So, also, among *external* causes, the stimulus of electricity, or the mechanical influence of a blow, concussion, or pressure, excites in the eye the sensation of light and colors; in the ear, a sense of a loud sound or of ringing; in the tongue, a saline or acid taste; and in the other parts of the body, a perception of peculiar jarring or of the mechanical impression, or a shock like it.

Sensations and Perceptions.—The habit of constantly referring our sensations to external causes, leads us to interpret the various modifications which external objects produce in our sensations, as *properties* of the external bodies themselves. Thus we speak of certain substances as possessing a disagreeable taste and smell; whereas, the fact is, their taste and smell are only disagreeable to *us*. It is evident, however, that on this habit of referring our sensations to causes outside ourselves (perception), depends the reality of the external world to us; and more especially is this the case with the senses of touch and sight. By the co-operation of these two senses aided by the others, we are enabled gradually to attain a knowledge of external objects which daily experience confirms, until we come to place unbounded confidence in hat is termed the "evidence of the senses."

Judgments.—We must draw a distinction between mere sensations, and the judgments based, often unconsciously, upon them. Thus, in looking at a near object, we unconsciously estimate its distance, and say it seems to be ten or twelve feet off: but the estimate of its distance is in reality a *judgment* based on many things besides the appearance of the object itself; among which may be mentioned the number of intervening objects, the number of steps which from past experience we know we must take before we could touch it, and many others.

Symptoms of Irritation of Nerves of Special Sense.—Irritation of the optic nerve, as by cutting it, invariably produces a sensation of light, of the auditory nerve a sensation of some modification of sound. Doubtless these distinct sensations depend not on any specialty in the structure of the nerves of special sense, but on the nature of their connections in the sensorium.

Experiments seem to have proved that none of these nerves possess the faculty of common sensibility. Thus, Magendie observed that when the olfactory nerves, laid bare in a dog, were pricked, no signs of pain were manifested; and other experiments of his seem to show that both the retina and optic nerve are insusceptible of pain. Further, the optic nerve is insusceptible to the stimulus of light when severed from its connection with the retina, which alone is adapted to receive luminous impressions.

Sensation of Motion is, like motion itself, of two kinds,—progressive and vibratory. The faculty of the perception of progressive motion is possessed chiefly by the senses of vision, touch, and taste. Thus an impression is perceived traveling from one part of the retina to another, and the movement of the image is interpreted by the mind as the motion of the object. The same is the case in the sense of touch; so also the movement of a sensation of taste over the surface of the organ of taste, can be recognized. The motion of tremors, or vibrations, is perceived by several senses, but especially by those of hearing and touch.

Sensations of Chemical Actions.—We are made acquainted with *chemical actions* principally by taste, smell, and touch, and by each of these senses in the mode proper to it. Volatile bodies, disturbing the conditions of the nerves by a chemical action, exert the greatest influence upon the organ of smell; and many matters act on that sense which produce no impression upon the organs of taste and touch,—for example, many odorous substances, as the vapor of metals, such as lead, and the vapor of many minerals. Some volatile substances, however, are perceived not only by the sense of smell, but also by the senses of touch and taste. Thus, the vapors of horse-radish and mustard, and acrid suffocating gases, act upon the conjunctiva and the mucous membrane of the lungs, exciting, through the common sensory nerves, merely modifications of common feeling; and at the same time they excite the sensations of smell and of taste.

SPECIAL SENSES—TOUCH.

Seat.—The sense of touch is not confined to particular parts of the body of small extent, like the other senses; on the contrary, all parts capable of perceiving the presence of a stimulus by ordinary sensation are, in certain degrees, the seat of this sense; for touch is simply a modification or exaltation of common sensation or sensibility. The nerves on which the sense of touch depends are, therefore, the same as those which confer ordinary sensation on the different parts of the body, viz., those derived from the posterior roots of the nerves of the spinal cord, and the sensory cerebral nerves.

But, although all parts of the body supplied with sensory nerves are thus, in some degree, organs of touch, yet the sense is exercised in perfection only in those parts the sensibility of which is extremely delicate, *e.g.*, the skin, the tongue, and the lips, which are provided with abundant papillæ. A peculiar and, of its own kind in each case, a very acute sense of touch is exercised through the medium of the nails and teeth. To a less extent the hair may be reckoned an organ of touch; as in the case of the eyelashes. The sense of touch renders us conscious of the presence of a stimulus, from the slightest to the most intense degree of its action, by that indescribable something which we call feeling, or common sensation. The modifications of this sense often depend on the extent of the parts affected. The sensation of pricking, for example, informs us that the sensitive particles are intensely affected in a small extent; the sensation of pressure indicates a slighter affection of the parts in the greater extent, and to a greater depth. It is by the depth to which the parts are affected that the feeling of pressure is distinguished from that of mere contact. Schiff and Brown-Séquard are of opinion that common sensibility and tactile sensibility manifest themselves to the individual by the aid of different sets of fibres. Sieveking has arrived at the same conclusion from pathological observation.

Varieties.—(*a*) The sense of *touch*, strictly so-called (tactile sensibility), (*b*) the sense of *pressure*, (*c*) the sense of *temperature*. These when carried beyond a certain degree are merged in (*d*) the sensation of *pain*.

Various peculiar sensations, such as *tickling*, must be classed with pain under the head of common sensations, since they give us no information as to external objects. Such sensations, whether pleasurable or painful, are in all cases referred by the mind to the part affected, and not to the cause which stimulates the sensory nerves of the part. The sensation of tickling may be produced in many parts of the body, but with especial intensity in the soles of the feet. Among other sensations belonging to this class, and confined to particular parts of the body, may be mentioned those of the genital organs and nipples.

(*a*) **Touch proper.**—In almost all parts of the body which have delicate tactile sensibility the epidermis, immediately over the papillæ, is moderately thin. When its thickness is much increased, as over the heel, the sense of touch is very much dulled. On the other hand, when it is altogether removed, and the cutis laid bare, the sensation of contact is replaced by one of pain. Further, in all highly sensitive parts, the papillæ are numerous and highly vascular, and usually the sensory nerves are connected with special End-organs, such as have been described (p. 337, Vol. I.).

The acuteness of the sense of touch depends very largely on the cutaneous circulation, which is of course largely influenced by external temperature. Hence the numbness, familiar to every one, produced by the application of cold to the skin.

Special organs of touch are present in most animals, among which may be mentioned the antennæ of insects, the "whiskers" (vibrissæ) of cats and other carnivora, the wings of bats, the trunk of the elephant, and the hand of man.

Judgment of the Form and Size of Bodies.—By the sense of touch the mind is made acquainted with the size, form, and other external characters of bodies. And in order that these characters may be easily ascertained, the sense of touch is especially developed in those parts which can be readily moved over the surface of bodies. Touch, in its more limited sense, or the act of examining a body by the touch, consists merely in a voluntary employment of this sense combined with movement, and stands in the same relation to the sense of touch, or common sensibility, generally, as the act of seeking, following, or examining odors, does to the sense of smell. The hand is best adapted for it, by reason of its peculiarities of structure,—namely, its capability of pronation and supination, which enables it, by the movement of rotation, to examine the whole circumference of the body; the power it possesses of opposing the thumb to the rest of the hand, and the relative mobility of the fingers; and lastly from the abundance of the sensory terminal organs which it possesses. In forming a conception of the figure and extent of a surface, the mind multiplies the size of the hand or fingers used in the inquiry by the number of times which it is contained in the surface traversed; and by repeating this process with regard to the different dimensions of a solid body, acquires a notion of its cubical extent, but, of course, only an imperfect notion, as other senses, *e.g.*, the sight, are required to make it complete.

Acuteness of Touch.—The perfection of the sense of touch on different parts of the surface is proportioned to the power which such parts possess of distinguishing and isolating the sensations produced by two points placed close together. This power depends, at least in part, on the number of primitive nerve-fibres distributed to the part; for the fewer the primitive fibres which an organ receives, the more likely is it that several impressions on different contiguous points will act on only one nervous fibre, and hence be confounded, and perhaps produce but one sensation. Experiments have been made to determine the tactile properties of different parts of the skin, as measured by this power of distinguishing distances. These consist in touching the skin, while the eyes are closed, with the points of a pair of compasses sheathed with cork, and in ascertaining how close the points of compasses might be brought to each other, and still be felt as two bodies. (E. H. Weber, Valentin.)

Table of variations in the tactile sensibility of different parts. —*The measurement indicates the least distance at which the two blunted points of a pair of compasses could be separately distinguished.* (E. H. Weber.)

Tip of tongue	1/24	inch
Palmar surface of third phalanx of forefinger	1/12	"
Palmar surface of second phalanges of fingers	1/6	"
Red surface of under-lip	1/6	"
Tip of the nose	1/4	"
Middle of dorsum of tongue	1/3	"
Palm of hand	5/12	"
Centre of hard palate	1/2	"
Dorsal surface of first phalanges of fingers	7/12	"
Back of hand	1 1/6	"
Dorsum of foot near toes	1 1/2	"
Gluteal region	1 1/2	"
Sacral region	1 1/2	"
Upper and lower parts of forearm	1 1/2	"
Back of neck near occiput	2	"
Upper dorsal and mid-lumbar regions	2	"
Middle part of forearm	2 1/2	"
Middle of thigh	2 1/2	"
Mid cervical region	2 1/2	"
Mid dorsal region	2 1/2	"

Moreover, in the case of the limbs, it was found that before they were recognized as two, the points of the compasses had to be *further* separated when the line joining them was in the long axis of the limb, than when in the transverse direction.

According to Weber the mind estimates the distance between two points by the number of unexcited nerve-endings which intervene between the two points touched. It would appear that a certain number of intervening unexcited nerve-endings are necessary before two points touched can be recognized as separate, and the greater this number the more clearly are the points of contact distinguished as separate. By practice the delicacy of a sense of touch may be very much increased. A familiar illustration occurs in the case of the blind, who, by constant practice, can acquire the power of reading raised letters the forms of which are almost if not quite undistinguishable, by the sense of touch, to an ordinary person.

The power of correctly localizing sensations of touch is gradually derived from experience. Thus infants when in pain simply cry, but make no effort to remove the cause of irritation, as an older child or adult would, doubtless on account of their imperfect knowledge of its exact situation. By long experience this power of localization becomes perfected, till at length the brain possesses a complete "picture" as it were of the surface of the body, and is able with marvellous exactness to localize each sensation of touch.

Illusions of Touch.—The different degrees of sensitiveness possessed by different parts may give rise to errors of judgment in estimating the distance between two points where the skin is touched. Thus, if blunted points of a pair of compasses (maintained at a constant distance apart) be slowly drawn over the skin of the cheek toward the lips, it is almost impossible to resist the conclusion that the distance between the points is gradually increasing. When they reach the lips they seem to be considerably further apart than on the cheek. Thus, too, our estimate of the size of a cavity in a tooth is usually exaggerated when based upon sensation derived from the tongue alone. Another curious illusion may here be mentioned. If we close the eyes, and place a small marble or pea between the crossed fore and middle fingers, we seem to be touching two marbles. This illusion is due to an error of judgment. The marble is touched by two surfaces which, under ordinary circumstances, could only be touched by two separate marbles, hence the mind, taking no cognizance of the fact that the fingers are crossed, forms the conclusion that two sensations are due to two marbles.

(*b*) **Pressure.**—It is extremely difficult to separate touch proper from sensations of pressure, and, indeed, the former may be said to depend upon the latter. If the hand be rested on the table and a very light body such as a small card placed on it, the only sensation produced is one of contact; if, however, an ounce weight be laid on the card an additional sensation (that of pressure) is experienced, and this becomes more intense as the weight is increased. If now the weight be raised by the hand, we are conscious of overcoming a certain resistance; this consciousness is due to what is termed the "*muscular sense*" (p. 119, Vol. II.). The estimate of a weight is, therefore, usually based on *two* sensations, (1) of pressure on the skin, and (2) the muscular sense.

The estimate of weight derived from a combination of these two sensations (as in lifting a weight) is more accurate than that derived from the former alone (as when a weight is laid on the hand); thus Weber found that by the former method he could generally distinguish 19½ oz. from 20 oz., but not 19¾ oz. from 20 oz., while by the latter he could at most only distinguish 14½ oz. from 15 oz.

It is not the absolute, but the relative, amount of the difference of weight which we have thus the faculty of perceiving.

It is not, however, certain, that our idea of amount of muscular force used is derived solely from sensation in the muscles. We have the power of estimating very accurately beforehand, and of regulating, the amount of nervous influence necessary for the production of a certain degree of movement. When we raise a vessel, with the contents of which we are not acquainted, the force we employ is determined by the idea we have conceived of its weight. If it should happen to contain some very heavy substance, as quicksilver, we shall probably let it fall; the amount of muscular action, or of nervous energy, which we had exerted being insufficient. The same thing occurs sometimes to a person descending stairs in the dark; he makes the movement for the descent of a step which does not exist. It is possible that in the same way the idea of weight and pressure in raising bodies, or in resisting forces, may in part arise from a consciousness of the amount of nervous energy transmitted from the brain rather than from a sensation in the muscles themselves. The mental conviction of the inability longer to support a weight must also be distinguished from the actual sensation of fatigue in the muscles.

So, with regard to the ideas derived from sensations of touch combined with movements, it is doubtful how far the consciousness of the extent of muscular movement is obtained from sensations in the muscles themselves. The sensation of movement attending the motions of the hand is very slight; and persons who do not know that the action of particular muscles is necessary for the production of given movements, do not suspect that the movement of the fingers, for example, depends on an action in the forearm. The mind has, nevertheless, a very definite knowledge of the changes of position produced by movements; and it is on this that the ideas which it conceives of the extension and form of a body are in great measure founded.

(*c*) **Temperature.**—The whole surface of the body is more or less sensitive to differences of temperature. The sensation of heat is distinct from that of touch; and it would seem reasonable to suppose that there are special nerves and nerve-endings for temperature. At any rate the power of discriminating temperature may remain unimpaired when the sense of touch is temporarily in abeyance. Thus if the ulnar nerve be compressed at the elbow till the sense of touch is very much dulled in the fingers which it supplies, the sense of temperature remains quite unaffected (Nothnagel).

The sensations of heat and cold are often exceedingly fallacious, and in many cases are no guide at all to the absolute temperature as indicated by a thermometer. All that we can with safety infer from our sensations of temperature, is that a given object is warmer or cooler than the skin. Thus the temperature of our skin is the standard; and as this varies from hour to hour according to the activity of the cutaneous circulation, our estimate of the absolute temperature of any body must necessarily vary too. If we put the left hand into water at 40° F. and the right into water at 110° F. and then immerse both in water at 80° F., it will feel warm to the left hand but cool to the right. Again, a piece of metal which has really the same temperature as a given piece of wood will feel much colder, since it conducts away the heat much more rapidly. For the same reason air in motion feels very much cooler than air of the same temperature at rest.

Perhaps the most striking example of the fallaciousness of our sensations as a measure of temperature is afforded by fever. In a shivering fit of ague the patient feels excessively cold, whereas his actual temperature is several degrees above the normal, while in the sweating stage which succeeds it he feels very warm, whereas really his temperature has fallen several degrees. In the former case the cutaneous circulation is much diminished, in the latter much increased; hence the sensations of cold and heat respectively.

In some cases we are able to form a fairly accurate estimate of absolute temperature. Thus, by plunging the elbow into a bath, a practised bath-attendant can tell the temperature sometimes within 1° F.

The temperatures which can be readily discriminated are between 50°—115° F. (10°—45° C.); very low and very high temperature alike produce a burning sensation. A temperature appears higher according to the extent of cutaneous surface exposed to it. Thus, water of a temperature which can be readily borne by the hand, is quite intolerable if the whole body be immersed. So, too, water appears much hotter to the hand than to a single finger.

The delicacy of the sense of temperature coincides in the main with that of touch, and appears to depend largely on the thickness of the skin; hence, in the elbow where the skin is thin, the sense of temperature is delicate, though that of touch is not remarkably so. Weber has further ascertained the following facts: two compass points so near together on the skin that they produce but a single impression, at once give rise to *two* sensations, when one is hotter than the other. Moreover, of two bodies of equal weight, that which is the colder feels heavier than the other.

As every sensation is attended with an idea, and leaves behind it an idea in the mind which can be reproduced at will, we are enabled to compare the idea of a past sensation with another sensation really present. Thus we can compare the weight of one body with another which we had previously felt, of which the idea is retained in our mind. Weber was indeed able to distinguish in this manner between temperatures, experienced one after the other, better than between temperatures to which the two hands were simultaneously subjected. This power of comparing present with past sensations diminishes, however, in proportion to the time which has elapsed between them. *After-sensations* left by impressions on nerves of common sensibility or touch are very vivid and durable. As long as the condition into which the stimulus has thrown the organ endures, the sensation also remains, though the exciting cause should have long ceased to act. Both painful and pleasurable sensations afford many examples of this fact.

Subjective sensations, or sensations dependent on internal causes, are in no sense more frequent than in the sense of touch. All the sensations of pleasure and pain, of heat and cold, of lightness and weight, of fatigue, etc., may be produced by internal causes. Neuralgic pains, the sensation of rigor, formication or the creeping of ants, and the states of the sexual organs occurring during sleep, afford striking examples of subjective sensations. The mind has a remarkable power of exciting sensations in the nerves of common sensibility; just as the thought of the nauseous excites sometimes the sensation of nausea, so the idea of pain gives rise to the actual sensation of pain in a part predisposed to it; numerous examples of this influence might be quoted.

TASTE.

Conditions Necessary.—The conditions for the perceptions of taste are:—1, the presence of a nerve and nerve-centre with special endowments; 2, the excitation of the nerve by the sapid matters, which for this purpose must be in a state of solution. The nerves concerned in the production of the sense of taste have been already considered (pp. 142 and 146, Vol. II.). The mode of action of the substances which excite taste consists in the production of a change in the condition of the gustatory nerves, and the conduction of the stimulus thus produced to the nerve-centre; and, according to the difference of the substances, an infinite variety of changes of condition of the nerves, and consequently of stimulations of the gustatory centre, may be induced. The matters to be tasted must either be in solution or be soluble in the moisture covering the tongue; hence insoluble substances are usually tasteless, and produce merely sensations of touch. Moreover, for the perfect action of a sapid, as of an odorous substance, it is necessary that the sentient surface should be moist. Hence, when the tongue and fauces are dry, sapid substances, even in solution, are with difficulty tasted.

The nerves of taste, like the nerves of other special senses, may have their peculiar properties excited by various other kinds of irritation, such as electricity and mechanical impressions. Thus, Henle observed that a small current of air directed upon the tongue gives rise to a cool saline taste, like that of saltpetre; and Baly has shown that a distinct sensation of taste, similar to that caused by electricity, may be produced by a smart tap applied to the papillæ of the tongue. Moreover, the mechanical irritation of the fauces and palate produces the sensation of nausea, which is probably only a modification of taste.

Seat of Sensation.—The principal seat of the sense of taste is the tongue. But the results of experiments as well as ordinary experience show that the soft palate and its arches, the uvula, tonsils, and probably the upper part of the pharynx, are endowed with taste. These parts, together with the base and posterior parts of the tongue, are supplied with branches of the glosso-pharyngeal nerve, and evidence has been already adduced that the sense of taste is conferred upon them by this nerve. In most, though not in all persons, the anterior parts of the tongue, especially the edges and tip, are endowed with the sense of taste. The middle of the dorsum is only feebly endowed with this sense, probably because of the density and thickness of the epithelium covering the filiform papillæ of this part of the tongue, which will prevent the sapid substances from penetrating to their sensitive parts. The gustatory property of the anterior part of the tongue is due, as already said (p. 142, Vol. II.), to the lingual or gustatory branch of the fifth nerve.

Structure of the Tongue.—The tongue is a muscular organ covered by mucous membrane. The muscles, which form the greater part of the substance of the tongue (*intrinsic* muscles) are termed *linguales;* and by these, which are attached to the mucous membrane chiefly, its smaller and more delicate movements are chiefly performed.

By other muscles (*extrinsic* muscles) as the genio-hyoglossus, the styloglossus, etc., the tongue is fixed to surrounding parts; and by this group of muscles its larger movements are performed.

The mucous membrane of the tongue resembles other mucous membranes (p. 322, Vol. I.) in essential points of structure, but contains *papillæ*, more or less peculiar to itself; peculiar, however, in details of structure and arrangement, not in their nature. The tongue is beset with numerous mucous follicles and glands. The use of the tongue in relation to mastication and deglutition has already been considered (pp. 226 and 238, Vol. I.).

The larger *papillæ* of the tongue are thickly set over the anterior two-thirds of its upper surface, or *dorsum* (Fig. 349), and give to it its characteristic roughness. In carnivorous animals, especially those of the cat tribe, the papillæ attain a large size, and are developed into sharp recurved horny spines. Such papillæ cannot be regarded as sensitive, but they enable the tongue to play the part of a most efficient rasp, as in scraping bones, or of a comb in cleaning their fur. Their greater prominence than those of the skin is due to their interspaces not being filled up with epithelium, as the interspaces of the papillæ of the skin are. The papillæ of the tongue present several diversities of form; but three principal varieties, differing both in seat and general characters, may usually be distinguished, namely, the (1) *circumvallate*, the (2) *fungiform*, and the (3) *filiform* papillæ. Essentially these have all of them the same structure, that is to say, they are all formed by a projection of the mucous membrane, and contain special branches of blood-vessels and nerves. In details of structure, however, they differ considerably one from another.

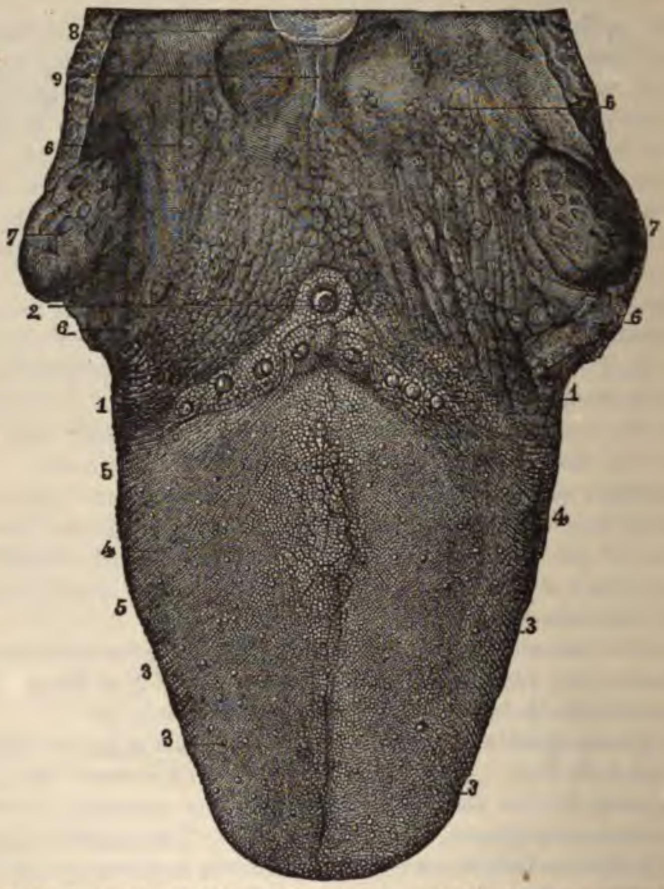


FIG. 349.—Papillar surface of the tongue, with the fauces and tonsils. 1, 1, circumvallate papillæ, in front of 2, the foramen cæcum; 3, fungiform papillæ; 4, filiform and conical papillæ; 5, transverse and oblique rugæ; 6, mucous glands at the base of the tongue and in the fauces; 7, tonsils; 8, part of the epiglottis; 9, median glosso-epiglottidean fold (frænum epiglottidis). (From Sappey.)

The surface of each kind is studded by minute conical processes of mucous membrane, which thus form secondary papillæ.

Simple papillæ also occur over most other parts of the tongue not occupied by the compound papillæ, and extend for some distance behind the papillæ circumvallatæ. The mucous membrane immediately in front of the epiglottis is, however, free from them. They are commonly buried beneath the epithelium; hence they are often overlooked.

(1.) *Circumvallate.*—These papillæ (Fig. 350), eight or ten in number, are situate in two V-shaped lines at the base of the tongue (1, 1, Fig. 349). They are circular elevations from $\frac{1}{20}$ to $\frac{1}{12}$th of an inch wide, each with a central depression, and surrounded by a circular fissure, at the outside of which again is a slightly elevated ring, both the central elevation and the ring being formed of close set simple papillæ (Fig. 350).

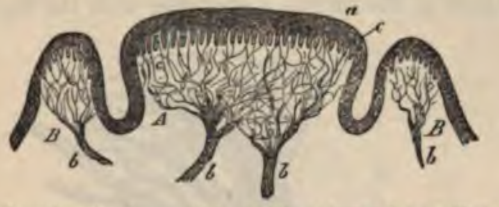


FIG. 350.—Vertical section of a circumvallate papilla 10·1.—A, the papillæ; B, the surrounding wall; *a*, the epithelial covering; *b*, the nerves of the papilla and wall spreading toward the surface; *c*, the secondary papillæ. (Kölliker.)

(2.) *Fungiform.*—The fungiform papillæ (3, Fig. 349) are scattered chiefly over the sides and tip, and sparingly over the middle of the dorsum, of the tongue; their name is derived from their being usually narrower at their base than at their summit. They also consist of groups of simple papillæ (A, Fig. 351), each of which contains in its interior a loop of capillary blood-vessels (B), and a nerve-fibre.

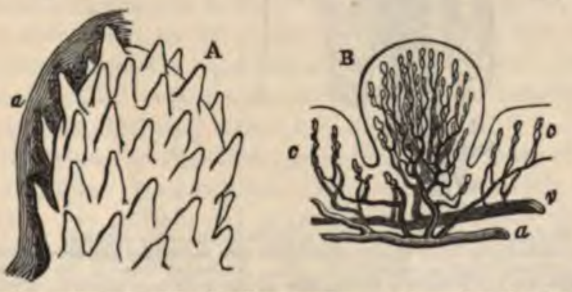


FIG. 351.—Surface and section of the fungiform papillæ. A, the surface of a fungiform papilla, partially denuded of its epithelium; *p*, secondary papillæ; *e*, epithelium. B, section of a fungiform papilla with the blood-vessels injected; *a*, artery; *v*, vein; *c*, capillary loops of similar papillæ in the neighboring structure of the tongue; *d*, capillary loops of the secondary papillæ; *e*, epithelium. (From Kölliker, after Todd and Bowman.)

(3.) *Conical or Filiform.*—These, which are the most abundant papillæ, are scattered over the whole surface of the tongue, but especially over the middle of the dorsum (Fig. 349). They vary in shape somewhat, but for the most part are conical or filiform, and covered by a thick layer of epidermis, which is arranged over them, either in an imbricated manner, or is prolonged from their surface in the form of fine stiff projections, hair-like in appearance, and in some instances in structure also (Fig. 352). From their peculiar structure, it seems likely that these papillæ have a mechanical function, or one allied to that of touch rather than of taste; the latter sense being probably seated especially in the ther two varieties of papillæ, the *circumvallate* and the *fungiform*.

The *epithelium* of the tongue is stratified with the upper layers of the squamous kind. It covers every part of the surface; but over the fungiform papillæ forms a thinner layer than elsewhere. The epithelium covering the filiform papillæ is extremely dense and thick, and, as before mentioned, projects from their sides and summits in the form of long, stiff, hair-like processes (Fig. 352). Many of these processes bear a close resemblance to hairs. Blood-vessels and nerves are supplied freely to the papillæ. The nerves in the fungiform and circumvallate papillæ form a kind of plexus, spreading out brush-wise (Fig. 350), but the exact mode of termination of the nerve-filaments is not certainly known.

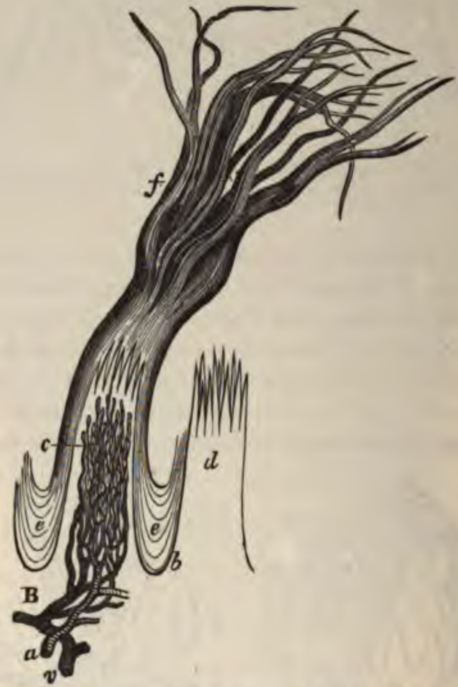


FIG. 352.—Two filiform papillæ, one with epithelium, the other without. 35-1.—*p*, the substance of the papillæ dividing at their upper extremities into secondary papillæ; *a*, artery, and *v*, vein, dividing into capillary loops; *e*, epithelial covering, laminated between the papillæ, but extended into hair-like processes, *f*, from the extremities of the secondary papillæ. (From Kölliker, after Todd and Bowman.)

Taste Goblets.—In the circumvallate papillæ of the tongue of man peculiar structures known as *gustatory buds* or *taste goblets,* have been discovered (Loven, Schwalbe). They are of an oval shape, and consist of a number of closely packed, very narrow and fusiform, cells (*gustatory cells*). This central core of gustatory cells is enclosed in a single layer of broader fusiform cells (*encasing cells*). The gustatory cells terminate in fine spikes not unlike cilia, which project on the free surface (Fig. 353).

These bodies also occur side by side in considerable numbers in the epithelium of the papilla foliata, which is situated near the root of the tongue in the rabbit, and also in man. Similar "taste-goblets" also occur pretty evenly distributed on the posterior (laryngeal) surface of the epiglottis (Verson, Schofield). It seems probable, from their distribution, that all these so-called taste-goblets are gustatory in function, though no nerves have been distinctly traced into them.

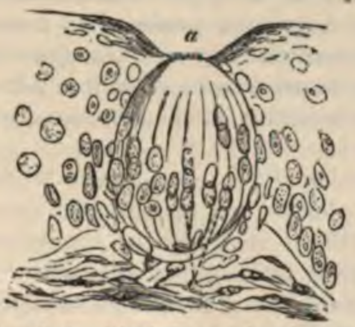


FIG. 353.—Taste-goblet from dog's epiglottis (laryngeal surface near the base), precisely similar in structure to those found in the tongue. *a*, depression in epithelium over goblet; below the letter are seen the fine hair-like processes in which the cells terminate; *c*, two nuclei of the axial (gustatory) cells. The more superficial nuclei belong to the superficial (encasing) cells; the converging lines indicate the fusiform shape of the encasing cells. × 400. (Schofield.)

Other Functions of the Tongue.—Besides the sense of taste, the tongue, by means also of its papillæ, is endued, (2) especially at its sides and tip, with a very delicate and accurate sense of touch (p. 164, Vol. II.), which renders it sensible of the impressions of heat and cold, pain and mechancial pressure, and consequently of the form of surfaces. The tongue may lose its common sensibility, and still retain the sense of taste, and *vice versâ.* This fact renders it probable that, although the senses of taste and of touch may be exercised by the same papillæ supplied by the same nerves, yet the nervous conductors for these two different sensations are distinct, just as the nerves for smell and common sensibility in the nostrils are distinct; and it is quite conceivable that the same nervous trunk may contain fibres differing essentially in their specific properties. Facts already detailed (p. 142, Vol. II.) seem to prove that the lingual branch of the fifth nerve is the conductor of sensations of taste in the anterior part of the tongue; and it is also certain, from the marked manifestations of pain to which its division in animals gives rise, that it is likewise a nerve of common sensibility. The glosso-pharyngeal also seems to contain fibres both of common sensation and of the special sense of taste.

The functions of the tongue in connection with (3) speech, (4) mastication, (5) deglutition, (6) suction, have been referred to in other chapters.

Taste and Smell; Perceptions.—The concurrence of common and special sensibility in the same part makes it sometimes difficult to determine whether the impression produced by a substance is perceived through the ordinary sensitive fibres, or through those of the sense of taste. In many cases, indeed, it is probable that both sets of nerve-fibres are concerned, as when irritating acrid substances are introduced into the mouth.

Much of the perfection of the sense of taste is often due to the sapid substances being also odorous, and exciting the simultaneous action of the sense of smell. This is shown by the imperfection of the taste of such substances when their action on the olfactory nerves is prevented by closing the nostrils. Many fine wines lose much of their apparent excellence if the nostrils are held close while they are drunk.

Varieties of Tastes.—Among the most clearly defined tastes are the sweet and bitter (which are more or less opposed to each other), the acid, alkaline, and saline tastes. Acid and alkaline taste may be excited by electricity. If a piece of zinc be placed beneath and a piece of copper above the tongue, and their ends brought into contact, an acid taste (due to the feeble galvanic current) is produced. The delicacy of the sense of taste is sufficient to discern 1 part of sulphuric acid in 1000 of water; but it is far surpassed in acuteness by the sense of smell.

After-tastes.—Very distinct sensations of taste are frequently left after the substances which excited them have ceased to act on the nerve; and such sensations often endure for a long time, and modify the taste of other substances applied to the tongue afterward. Thus, the taste of sweet substances spoils the flavor of wine, the taste of cheese improves it. There appears, therefore, to exist the same relation between tastes as between colors, of which those that are opposed or complementary render each other more vivid, though no general principles governing this relation have been discovered in the case of tastes. In the art of cooking, however, attention has at all times been paid to the consonance or harmony of flavors in their combination or order of succession, just as in painting and music the fundamental principles of harmony have been employed empirically while the theoretical laws were unknown.

Frequent and continued repetitions of the same taste render the perception of it less and less distinct, in the same way that a color becomes more and more dull and indistinct the longer the eye is fixed upon it.

Thus, after frequently tasting first one and then the other of two kinds of wine, it becomes impossible to discriminate between them.

The simple contact of a sapid substance with the surface of the gustatory organ seldom gives rise to a distinct sensation of taste; it needs to be diffused over the surface, and brought into intimate contact with the sensitive parts by compression, friction, and motion between the tongue and palate.

Subjective Sensations of Taste.—The sense of taste seems capable of being excited only by external causes, such as changes in the conditions of the nerves or nerve-centres, produced by congestion or other causes, which excite subjective sensations in the other organs of sense. But little is known of the subjective sensations of taste; for it is difficult to distinguish the phenomena from the effects of external causes, such as changes in the nature of the secretions of the mouth.

SMELL.

Conditions Necessary.—(1.) The first conditions essential to the sense of smell are a special *nerve* and *nerve-centre,* the changes in whose condition are perceived in sensations of odor; for no other nervous structure is capable of these sensations, even though acted on by the same causes. The same substance which excites the sensation of smell in the olfactory centre may cause another peculiar sensation through the nerves of taste, and may produce an irritating and burning sensation on the nerves of touch; but the sensation of odor is yet separate and distinct from these, though it may be simultaneously perceived. (2.) The second condition of smell is a peculiar change produced in the olfactory nerve and its centre by the stimulus or odorous substance. (3.) The material causes of odors are, usually, in the case of animals living in the air, either solids suspended in a state of extremely fine division in the atmosphere; or gaseous exhalations often of so subtile a nature that they can be detected by no other re-agent than the sense of smell itself. The matters of odor must, in all cases, be dissolved in the mucus of the mucous membrane before they can be immediately applied to, or affect the olfactory nerves; therefore a further condition necessary for the perception of odors is, that the mucous membrane of the nasal cavity be moist. When the Schneiderian membrane is dry, the sense of smell is impaired or lost; in the first stage of catarrh, when the secretion of mucus within the nostrils is lessened, the faculty of perceiving odor is either lost or rendered very imperfect. (4.) In animals living in the air, it is also requisite that the odorous matter should be transmitted in a current through the nostrils. This is effected by an inspiratory movement, the mouth being closed; hence we have voluntary influence over the sense of smell; for by interrupting respiration we prevent the perception of odors, and by repeated quick inspiration, assisted, as in the act of *sniffing*, by the action of the nostrils, we render the impression more intense (see p. 201, Vol. I.). An odorous substance in a liquid form injected into the nostrils appears incapable of giving rise to the sensation of smell: thus Weber could not smell the slightest odor when his nostrils were completely filled with water containing a large quantity of eau de Cologne.

Seat of the Sense of Smell.—The human organ of smell is formed by the filaments of the olfactory nerves, distributed in the mucous membrane covering the upper third of the septum of the nose, the superior turbinated or spongy bone, the upper part of the middle turbinated bone, and the upper wall of the nasal cavities beneath the cribriform plates of the ethmoid bones (Figs. 354 and 355). The olfactory region is covered by cells of *cylindrical* epithelium, prolonged at their deep extremities into fine branched processes, but not ciliated; and interspersed with these are fusiform (*olfactory*) cells, with both superficial and deep processes (Fig. 356), the latter being probably connected with the terminal filaments of the olfactory nerve. The lower, or respiratory part, as it is called, of the nasal fossæ is lined by *cylindrical ciliated* epithelium, except in the region of the nostrils, where it is *squamous*. The branches of the olfactory nerves retain much of the same soft and greyish texture which distinguishes those of the olfactory *tracts* within the cranium. Their filaments, also, are peculiar, more resembling those of the sympathetic nerve than the filaments of the other cerebral nerves do, containing no outer white substance, and being finely granular and nucleated. The sense of smell is derived exclusively through those parts of the nasal cavities in which the olfactory nerves are distributed; the accessory cavities or sinuses communicating with the nostrils seem to have no relation

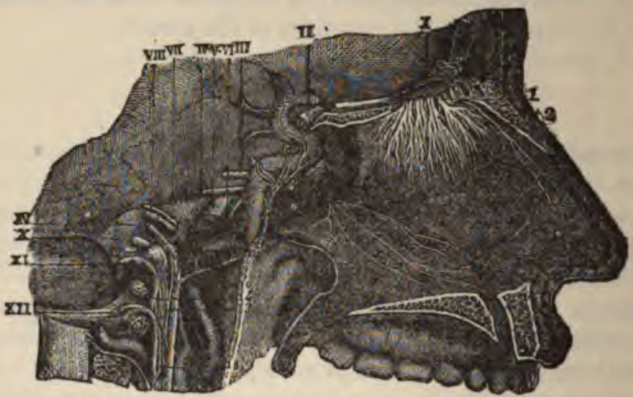


FIG. 354.—Nerves of the septum nasi, seen from the right side. ⅔.—I, the olfactory bulb; 1, the olfactory nerves passing through the foramina of the cribriform plate, and descending to be distributed on the septum; 2, the internal or septal twig of the nasal branch of the ophthalmic nerve; 3, naso-palatine nerves. (From Sappey, after Hirschfeld and Leveillé.)

to it. Air impregnated with the vapor of camphor was injected into the frontal sinus through a fistulous opening, and odorous substances have been injected into the antrum of Highmore; but in neither case was any odor perceived by the patient. The purposes of these sinuses appear to be, that the bones, necessarily large for the action of the muscles and other parts connected with them, may be as light as possible, and that there may be more room for the resonance of the air in vocalizing. The former purpose, which is in other bones obtained by filling their cavities with fat, is here attained, as it is in many bones of birds, by their being filled with air.

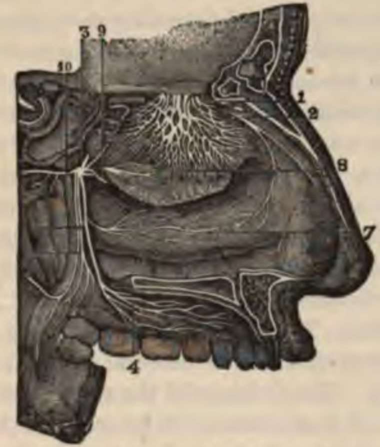


FIG. 355.—Nerves of the outer walls of the nasal fossæ. 3-5.—1, network of the branches of the olfactory nerve, descending upon the region of the superior and middle turbinated bones; 2, external twig of the ethmoidal branch of the nasal nerves; 3, spheno-palatine ganglion; 4, ramification of the anterior palatine nerves; 5, posterior, and 6, middle divisions of the palatine nerves; 7, branch to the region of the inferior turbinated bone; 8, branch to the region of the superior and middle turbinated bones; 9, naso-palatine branch to the septum cut short. (From Sappey, after Hirschfeld and Leveillé.)

Other Functions of the Olfactory Region.—All parts of the nasal cavities, whether or not they can be the seat of the sense of smell, are endowed with common sensibility by the nasal branches of the first and second divisions of the fifth nerve. Hence the sensations of cold, heat, itching, tickling, and pain; and the sensation of tension or pressure in the nostrils. That these nerves cannot perform the function of the olfactory nerves is proved by cases in which the sense of smell is lost, while the mucous membrane of the nose remains susceptible of the various modifications of common sensation or touch. But it is often difficult to distinguish the sensation of smell from that of mere feeling, and to ascertain what belongs to each separately. This is the case particularly with the sensations excited in the nose by acrid vapors, as of ammonia, horse-radish, mustard, etc., which resemble much the sensations of the nerves of touch; and the difficulty is the greater, when it is remembered that these acrid vapors have nearly the same action upon the mucous membrane of the eyelids. It was because the common sensibility of the nose to these irritating substances remained after the destruction of the olfactory nerves, that Magendie was led to the erroneous belief that the fifth nerve might exercise this special sense.

Varieties of Odorous Sensations.—Animals do not all equally perceive the same odors; the odors most plainly perceived by an herbivorous animal and by a carnivorous animal are different. The Carnivora have the power of detecting most accurately by the smell the special peculiarities of animal matters, and of tracking other animals by the scent; but have apparently very little sensibility to the odors of plants and flowers. Herbivorous animals are peculiarly sensitive to the latter, and have a narrower sensibility to animal odors, especially to such as proceed from other individuals than their own species. Man is far inferior to many animals of both classes in respect of the acuteness of smell; but his sphere of susceptibility to various odors is more uniform and extended. The cause of this difference lies probably in the endowments of the cerebral parts of the olfactory apparatus. The delicacy of the sense of smell is most remarkable; it can discern the presence of bodies in quantities so minute as to be undiscoverable even by spectrum analysis; $\frac{3}{100,000,000}$ of a grain of musk can be distinctly smelt (Valentin). Opposed to the sensation of an agreeable odor is that of a disagreeable or disgusting odor, which corresponds to the sensations of pain, dazzling and disharmony of colors, and dissonance in the other senses. The cause of this difference in the effect of different odors is unknown: but this much is certain, that odors are pleasant or offensive in a relative sense only, for many animals pass their existence in the midst of odors which to us are highly disagreeable. A great difference in this respect is, indeed, observed amongst men: many odors, generally thought agreeable, are to some persons intolerable; and different persons describe differently the sensations that they severally derive from the same odorous substances. There seems also to be in some persons an insensibility to certain odors, comparable with that of the eye to certain colors; and among different persons, as great a difference in the acuteness of the sense of smell as among others in the acuteness of sight. We have no exact proof that a relation of harmony and disharmony exists between odors as between colors and sounds; though it is probable that such is the case, since it certainly is so with regard to the sense of taste; and since such a relation would account in some measure for the different degrees of perceptive power in different

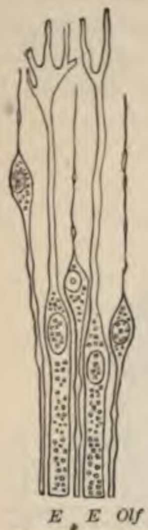


FIG. 356.—Epithelial and olfactory cells of man. The letters are placed on the free surface. *E*, *E*, epithelial cells; *Olf.*, olfactory cells. (Max Schultze.)

persons; for as some have no ear for music (as it is said), so others have no clear appreciation of the relation of odors, and therefore little pleasure in them.

Subjective Sensations of Smell.—The sensations of the olfactory nerves, independent of the external application of odorous substances, have hitherto been little studied. The friction of the electric machine produces a smell like that of phosphorus. Ritter, too, has observed, that when galvanism is applied to the organ of smell, besides the impulse to sneeze, and the tickling sensation excited in the filaments of the fifth nerve, a smell like that of ammonia was excited by the negative pole, and an acid odor by the positive pole; whichever of these sensations were produced, it remained constant as long as the circle was closed, and changed to the other at the moment of the circle being opened. *Subjective* sensations occur frequently in connection with the sense of smell. Frequently a person smells something which is not present, and which other persons cannot smell; this is very frequent with nervous people, but it occasionally happens to every one. In a man who was constantly conscious of a bad odor, the arachnoid was found after death to be beset with deposits of bone; and in the middle of the cerebral hemispheres were scrofulous cysts in a state of suppuration. Dubois was acquainted with a man who, ever after a fall from his horse, which occurred several years before his death, believed that he smelt a bad odor.

HEARING.

Anatomy of the Ear.—For descriptive purposes, the Ear, or Organ of Hearing, is divided into three parts, (1) the *external*, (2) the *middle*, and (3) the *internal* ear. The two first are only accessory to the third or internal ear, which contains the essential parts of an organ of hearing. The accompanying figure shows very well the relation of these divisions,—one to the other (Fig. 357).

(1.) *External Ear.*—The external ear consists of the *pinna* or *auricle*, and the external *auditory canal* or *meatus*.

The principal parts of the *pinna* (Fig. 358, A) are two prominent rims enclosed one within the other (*helix* and *antihelix*), and enclosing a central hollow named the *concha;* in front of the concha, a prominence directed backward, the *tragus*, and opposite to this, one directed forward, the *antitragus*. From the concha, the auditory canal, with a slight arch directed upward, passes inward and a little forward to the membrana tympani, to which it thus serves to convey the vibrating air. Its outer part consists of fibro-cartilage continued from the concha; its inner part of bone. Both are lined by skin continuous with that of the pinna, and extending over the outer part of the *membrana tympani.*

Toward the outer part of the canal are fine hairs and sebaceous glands, while deeper in the canal are small glands, resembling the sweat-glands in structure, which secrete a peculiar yellow substance called *cerumen*, or ear-wax.

(2.) *Middle Ear* or *Tympanum.*—The *middle* ear, or *tympanum* (3, Fig. 357), is separated by the *membrana tympani* from the external auditory canal. It is a cavity in the temporal bone, opening through its anterior and inner wall into the Eustachian tube, a cylindriform flattened canal, dilated at both ends, composed partly of bone and partly of cartilage, and lined with mucous membrane, which forms a communication between the tympanum and the pharynx. It opens into the cavity of the pharynx just behind the posterior aperture of the nostrils. The cavity of the tympanum communicates posteriorly with air-cavities, the *mastoid cells* in the mastoid process of the temporal bone; but its only opening to the external air is through the Eustachian tube (4, Fig. 357). The walls of the tympanum are osseous, except where apertures in them are closed with membrane, as at the fenestra rotunda, and fenestra ovalis, and at the outer part where the bone is replaced by the *membrana tympani.* The cavity of the tympanum is lined with mucous membrane, the epithelium of which is ciliated and continuous with that of the pharynx.

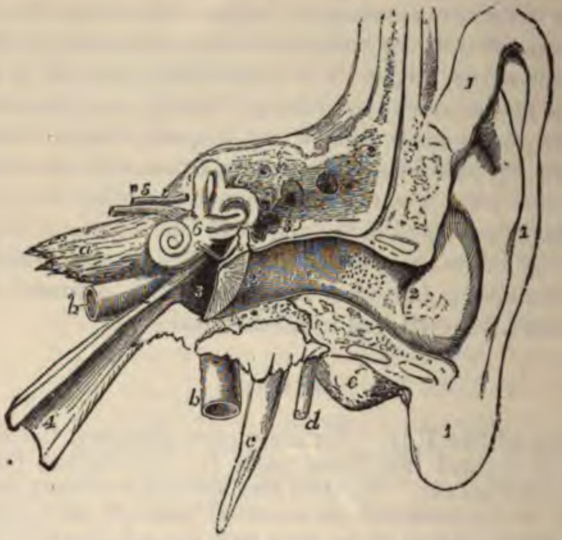


FIG. 357.—Diagrammatic view from before of the parts composing the organ of hearing of the left side. The temporal bone of the left side, with the accompanying soft parts, has been detached from the head, and a section has been carried through it transversely, so as to remove the front of the meatus externus, half the tympanic membrane, the upper and anterior wall of the tympanum and Eustachian tube. The meatus internus has also been opened, and the bony labyrinth exposed by the removal of the surrounding parts of the petrous bone. 1, the pinna and lobe; 2, 2', meatus externus; 2', membrana tympani; 3, cavity of the tympanum: 3', its opening backward into the mastoid cells; between 3 and 3', the chain of small bones; 4, Eustachian tube; 5, meatus internus, containing the facial (uppermost) and the auditory nerves; 6, placed on the vestibule of the labyrinth above the fenestra ovalis; *a*, apex of the petrous bone; *b*, internal carotid artery; *c*, styloid process; *d*, facial nerve issuing from the stylo-mastoid foramen; *e*, mastoid process; *f*, squamous part of the bone covered by integument, etc. (Arnold.)

It contains a chain of small bones (*ossicula auditus*) which extends from the membrana tympani to the fenestra ovalis.

The *membrana tympani* is placed in a slanting direction at the bottom of the external auditory canal, its plane being at an angle of about 45° with the lower wall of the canal. It is formed chiefly of a tough and tense fibrous membrane, the edges of which are set in a bony groove; its outer surface is covered with a continuation of the cutaneous lining of the auditory canal, its inner surface with part of the ciliated mucous membrane of the tympanum.

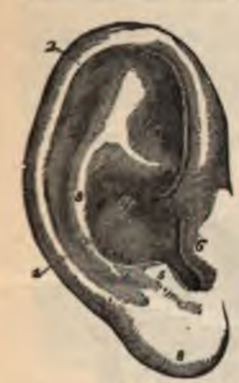


Fig. 358.—Outer surface of the pinna of the right auricle. 1, helix; 2, fossa of the helix; 3, antihelix; 4, fossa of the antihelix; 5, antitragus; 6, tragus; 7, concha; 8, lobule. ⅜.

The small bones or *ossicles* of the ear are three; named *malleus, incus,* and *stapes.* The *malleus,* or hammer-bone, is attached by a long slightly curved process, called its handle, to the membrana tympani; the line of attachment being vertical, including the whole length of the handle, and extending from the upper border to the centre of the membrane. The head of the malleus is irregularly rounded; its neck, or the line of boundary between it and the handle, supports two processes; a *short* conical one, which receives the insertion of the *tensor tympani,* and a *slender* one, *processus gracilis,* which extends forward, and to which the *laxator tympani* muscle is attached. The *incus,* or anvil-bone, shaped like a bicuspid molar tooth, is articulated by its broader part, corresponding with the surface of the crown of a tooth, to the malleus. Of its two fang-like processes, one, directed backward, has a free end lodged in a depression in the mastoid bone; the other, curved downward and more pointed, articulates by means of a roundish tubercle, formerly called *os orbiculare,* with the stapes, a little bone shaped exactly like a stirrup, of which the base or bar fits into the fenestra ovalis. To the neck of the stapes, a short process, corresponding with the loop of the stirrup, is attached the *stapedius* muscle.

The Ossicula.—The bones of the ear are covered with mucous membrane reflected over them from the wall of the tympanum; and are movable both altogether and one upon the other. The malleus moves and vibrates with every movement and vibration of the membrana tympani, and its movements are communicated through the incus to the stapes, and through it to the membrane closing the fenestra ovalis. The malleus, also, is movable in its articulation with the incus; and the membrana tympani moving with it is altered in its degree of tension by the laxator and tensor tympani muscles. The stapes is movable on the process of the incus, when the stapedius muscle acting, draws it backward. The axis round which the malleus and incus rotate is the line joining the processus gracilis of the malleus and the posterior (short) process of the incus.

(3.) *Internal Ear.*—The proper organ of hearing is formed by the distribution of the auditory nerve within the *internal ear,* or *labyrinth* of the ear, a set of cavities within the petrous portion of the temporal bone.

The bone which forms the walls of these cavities is denser than that around it, and forms the *osseous labyrinth;* the membrane within the cavities forms the *membranous labyrinth.* The membranous labyrinth contains a fluid called *endolymph;* while outside it, between it and the osseous labyrinth, is a fluid called *perilymph.*

The osseous labyrinth consists of three principal parts, namely, the *vestibule,* the *cochlea,* and the *semicircular canals.*

The vestibule is the middle cavity of the labyrinth and the central organ of the whole auditory apparatus. It presents, in its inner wall, several openings for the entrance of the divisions of the auditory nerve; in its outer wall, the *fenestra ovalis* (2, Fig. 359), an opening filled by the base of the *stapes,* one of the small bones of the ear; in its posterior and superior walls, five openings by which the *semicircular canals* communicate with it: in its anterior wall, an opening leading into the *cochlea.* The hinder part of the inner wall of the vestibule also presents an opening, the orifice of the *aquæductus vestibuli,* a canal leading to the posterior margin of the petrous bone, with uncertain contents and unknown purpose.

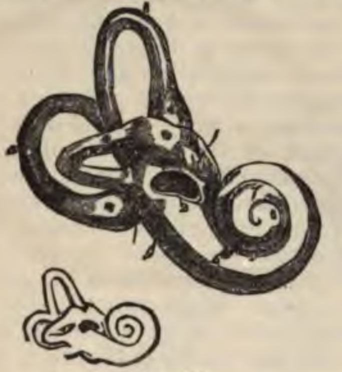


FIG. 359.

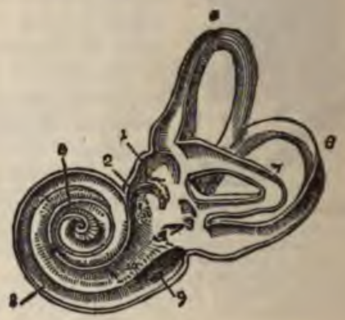


FIG. 360.

FIG. 359.—Right bony labyrinth, viewed from the outer side. The specimen here represented is prepared by separating piecemeal the looser substance of the petrous bone from the dense walls which immediately enclose the labyrinth. 1, the vestibule; 2, fenestra ovalis; 3, superior semicircular canal; 4, horizontal or external canal; 5, posterior canal; *, ampullæ of the semicircular canals; 6, first turn of the cochlea; 7, second turn; 8, apex; 9, fenestra rotunda. The smaller figure in outline below shows the natural size. $\frac{2\frac{1}{2}}{1}$. (Sömmering.)

FIG. 360.—View of the interior of the left labyrinth. The bony wall of the labyrinth is removed superiorly and externally. 1, fovea hemielliptica; 2, fovea hemispherica; 3, common opening of the superior and posterior semicircular canals; 4, opening of the aqueduct of the vestibule; 5, the superior, 6, the posterior, and 7, the external semicircular canals; 8, spiral tube of the cochlea (scala tympani); 9, opening of the aqueduct of the cochlea; 10, placed on the lamina spiralis in the scala vestibuli. $\frac{2\frac{1}{2}}{1}$ (Sömmering.)

The *semicircular canals* (Figs. 359, 360), are three arched cylindriform bony canals, set in the substance of the petrous bone. They all open at both ends into the vestibule (two of them first coalescing). The ends of each are dilated just before opening into the vestibule; and one end of each being more dilated than the other is called an *ampulla.* Two of the canals form nearly vertical arches; of these the superior is also anterior; the posterior is inferior; the third canal is horizontal, and lower and shorter than the others.

The *cochlea* (6, 7, 8, Figs. 359 and 360), a small organ, shaped like a common snail-shell, is seated in front of the vestibule, its base resting on the bottom of the internal meatus, where some apertures transmit to it the cochlear filaments of the auditory nerve. In its axis, the cochlea is traversed by a conical column, the *modiolus*, around which a *spiral canal* winds with about two turns and a half from the base to the apex. At the apex of the cochlea the canal is closed; at the base it presents three openings, of which one, already mentioned, communicates with the vestibule; another called *fenestra rotunda*, is separated by a membrane from the cavity of the tympanum; the third is the orifice of the *aquæductus cochleæ*, a canal leading to the jugular fossa of the petrous bone, and corresponding, at least in obscurity of purpose and origin, to the aquæductus vestibuli. The spiral canal is divided into two passages, or scalæ, by a partition of bone and membrane, the *lamina spiralis*. The osseous part or *zone* of this lamina is connected with the modiolus; the membranous part, with a muscular zone, according to Todd and Bowman, forming its outer margin, is attached to the outer wall of the canal. Commencing at the base of the cochlea, between its vestibular and tympanic openings, they form a partition between these apertures; the two scalæ are, therefore, in correspondence with this arrangement, named *scala vestibuli* and *scala tympani* (Fig. 361). At the apex of the cochlea, the lamina spiralis ends in a small *hamulus*, the inner and concave part of which, being detached from the summit of the modiolus, leaves a small aperture named *helicotrema*, by which the two scalæ, separated in all the rest of their length, communicate.

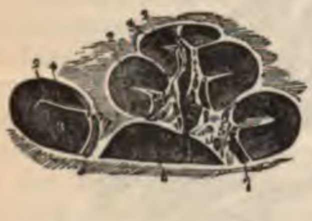


FIG. 361.

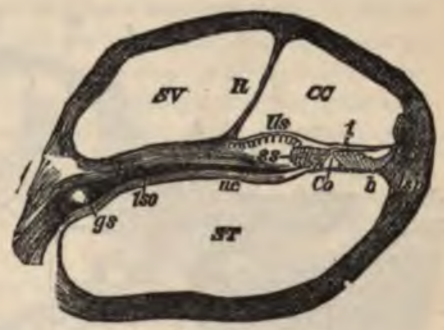


FIG. 362.

FIG. 361.—View of the osseous cochlea divided through the middle. 1, central canal of the modiolus; 2, lamina spiralis ossea; 3, scala tympani; 4, scala vestibuli; 5, porous substance of the modiolus near one of the sections of the canalis spiralis modioli. $\frac{5}{1}$. (Arnold.)

FIG. 362.—Section through one of the coils of the cochlea (diagrammatic). *S T*, scala tympani; *S V*, scala vestibuli; *C C*, canalis cochleæ or canalis membranaceus; *R*, membrane of Reissner; *l s o*, lamina spiralis ossea; *l l s*, limbus laminæ spiralis; *s s*, sulcus spiralis; *n c*, cochlear nerve; *g s*, ganglion spirale; *t*, membrana tectoria (below the membrana tectoria is the lamina reticularis); *b*, membrana basilaris; *Co*, rods of Corti; *l s p*, ligamentum spirale. (From *Quain's Anatomy*.)

Besides the "scala vestibuli" and "scala tympani," there is a third space between them, called *scala media* or *canalis membranaceus* (CC, Fig 362). In section it is triangular, its external wall being formed by the wall of the cochlea, its upper wall (separating it from the scala vestibuli) by the membrane of Reissner, and its lower wall (separating it from the scala tympani) by the basilar membrane, these two meeting at the outer edge of the bony lamina spiralis. Following the turns of the cochlea to its apex, the scala media there terminates blindly; while toward the base of the cochlea it is also closed with the exception of a very narrow passage (canalis reuniens) uniting it with the sacculus. The scala media (like the rest of the membranous labyrinth) contains "endolymph."

Organ of Corti.—Upon the basilar membrane are arranged cells of various shapes.

About midway between the outer edge of the lamina spiralis and the outer wall of the cochlea are situated the *rods of Corti*. Viewed sideways, the rods of Corti are seen to consist of an external and internal pillar, each rising from an expanded foot or *base* on the basilar membrane. They slant inward toward each other, and each ends in a swelling termed the head; the head of the inner pillar overlying that of the outer (Fig. 363). Each pair of pillars forms, as it were, a pointed roof arching over a space, and by a succession of them, a little tunnel is formed.

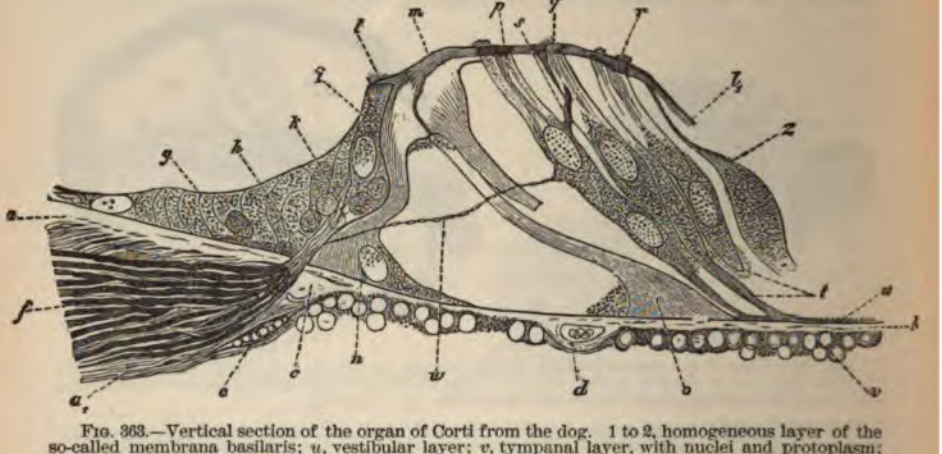


Fig. 363.—Vertical section of the organ of Corti from the dog. 1 to 2, homogeneous layer of the so-called membrana basilaris; *u*, vestibular layer; *v*, tympanal layer, with nuclei and protoplasm; *a*, prolongation of tympanal periosteum of lamina spiralis ossea; *c*, thickened commencement of the membrana basilaris near the point of perforation of the nerves *h*; *d*, blood-vessel, (vas spirale); *e*, blood-vessel; *f*, nerves; *g*, the epithelium of the sulcus spiralis internus; *i*, internal or tufted cell, with basil process *k*, surrounded with nuclei and protoplasm (of the granular layer), into which the nerve-fibres radiate; *l*, hairs of the internal hair-cell; *n*, base or foot of inner pillar of organ of Corti; *m*, head of the same uniting with the corresponding part of an external pillar, whose under half is missing, while the next pillar beyond, *o*, presents both middle portion and base; *r*, *s*, *d*, three external hair-cells; *t*, bases of two neighboring hair or tufted cells; *x*, so-called supporting cell of Hensen; *w*, nerve fibre terminating in the first of the external hair-cells; *l l* to *l*, lamina reticularis. × 800. (Waldeyer.)

It has been estimated that there are about 3000 of these pairs of pillars, in proceeding from the base of the cochlea toward its apex. They are found progressively to increase in length, and become more oblique; in other words, the tunnel becomes wider, but diminishes in height as we approach the apex of the cochlea. Leaning, as it were, against these external and internal pillars are certain other cells, of which the external ones terminate in small hair-like processes. Most of the above details are shown in the accompanying figure (Fig. 363). This complicated structure rests, as we have seen, upon the basilar membrane; it is roofed in by a remarkable fenestrated membrane (lamina reticularis of Kölliker), into the fenestræ of which the tops of the various rods and cells are received. When viewed from above, the organ of Corti shows a remarkable resemblance to the key-board of a piano. In close relation with the rods of Corti and the cells inside and outside them, and probably projecting by free ends into the little "tunnel" containing fluid (roofed in by them), are filaments of the auditory nerve.

Membranous Labyrinth.—This corresponds generally with the form of the osseous labyrinth, so far as regards the vestibule and semicircular canals, but is separated from the walls of these parts by fluid, except where the nerves enter into connection within it. As already mentioned, the membranous labyrinth contains a fluid called *endolymph;* and between its outer surface and the inner surface of the walls of the vestibule and semicircular canals is another collection of similar fluid, called *perilymph;* so that all the sonorous vibrations impressing the auditory nerves on these parts of the internal ear, are conducted through fluid to a membrane suspended in and containing fluid. In the cochlea, the membranous labyrinth completes the septum between the two *scalæ* and encloses a spiral canal, previously mentioned, called *canalis membranaceus* or *canalis cochleæ* (Fig. 362). The fluid in the *scalæ* of the cochlea is continuous with the perilymph in the vestibule and semicircular canals, and there is no fluid external to its lining membrane. The vestibular portion of the membranous labyrinth comprises two, probably communicating cavities, of which the larger and upper is named the *utriculus;* the lower, the *sacculus.* They are lodged in depressions in the bony labyrinth termed respectively "fovea hemielliptica" and "fovea hemispherica." Into the former open the orifices of the membranous semicircular canals; into the latter the *canalis cochleæ.* The membranous labyrinth of all these parts is laminated, transparent, very vascular, and covered on the inner surface with nucleated cells, of which those that line the ampullæ are prolonged into stiff hair-like processes; the same appearance, but to a much less degree, being visible in the *utricule* and *saccule.* In the cavities of the utriculus and sacculus are small masses of calcareous particles, *otoconia* or *otoliths;* and the same, although in more minute quantities, are to be found in the interior of some other parts of the membranous labyrinth.

Auditory Nerve.—For the appropriate exposure of the filaments of the auditory nerve to sonorous vibrations all the organs now described are provided. It is characterized as a nerve of special sense by its softness (whence it derived its name of *portio mollis* of the seventh pair) and by the fineness of its component fibres. It enters the labyrinth of the ear in two divisions; one for the vestibule and semicircular canals, and the other for the cochlea.

The branches for the vestibule spread out and radiate on the inner surface of the membranous labyrinth: their exact termination is unknown. Those for the semicircular canals pass into the ampullæ, and form, within each of them, a forked projection which corresponds with a septum in the interior of the ampulla. The branches for the cochlea enter it through orifices at the base of the modiolus, which they ascend, and thence successively pass into canals in the osseous part of the lamina spiralis. In the canals of this osseous part or zone, the nerves are arranged in a plexus, containing ganglion cells. Their ultimate termination is not known with certainty; but some of them, without doubt, end in the organ of Corti, probably in cells.

PHYSIOLOGY OF HEARING.

All the acoustic contrivances of the organ of hearing are means for conducting the sound, just as the optical apparatus of the eye are media for conducting the light. Since all matter is capable of propagating sonorous vibrations, the simplest conditions must be sufficient for mere hearing; for all substances surrounding the auditory nerve would communicate sound to it. The whole development of the organ of hearing, therefore, can have for its object merely the *rendering more perfect* the propagation of the sonorous vibrations, and their *multiplication* by resonance; and, in fact, all the acoustic apparatus of the organ may be shown to have reference to these two principles.

Functions of the External Ear.—The external auditory passage influences the propagation of sound to the tympanum in three ways:—1, by causing the sonorous undulations, entering directly from the atmosphere, to be transmitted by the air in the passage immediately to the membrana tympani, and thus preventing them from being dispersed; 2, by the walls of the passage conducting the sonorous undulations imparted to the external ear itself, by the shortest path to the attachment of the membrana tympani, and so to this membrane; 3, by the resonance of the column of air contained within the passage; 4, the external ear, especially when the tragus is provided with hairs, is also, doubtless, of service in protecting the meatus and membrana tympani against dust, insects, and the like.

1. As a conductor of undulations of air, the external auditory passage receives the direct undulations of the atmosphere, of which those that enter in the direction of its axis produce the strongest impressions. The undulations which enter the passage obliquely are reflected by its parietes, and thus by reflexion reach the membrana tympani.

2. The walls of the meatus are also solid conductors of sound; for those vibrations which are communicated to the cartilage of the external ear, and not reflected from it, are propagated by the shortest path through the parietes of the passage to the membrana tympani. Hence, both ears being close stopped, the sound of a pipe is heard more distinctly when its lower extremity, covered with a membrane, is applied to the cartilage of the external ear itself, than when it is placed in contact with the surface of the head.

3. The external auditory passage is important, inasmuch as the air which it contains, like all insulated masses of air, increases the intensity of sounds by resonance.

Regarding the cartilage of the external ear, therefore, as a conductor of sonorous vibrations, all its inequalities, elevations, and depressions, which are useless with regard to reflexion, become of evident importance; for those elevations and depressions upon which the undulations fall perpendicularly, will be affected by them in the most intense degree; and, in consequence of the various forms and positions of these inequalities, sonorous undulations, in whatever direction they may come, must fall perpendicularly upon the tangent of some one of them. This affords an explanation of the extraordinary form given to this part.

Functions of the Middle Ear.—In animals living in the atmosphere, the sonorous vibrations are conveyed to the auditory nerve by three different media in succession; namely, the air, the solid parts of the body of the animal and of the auditory apparatus, and the fluid of the labyrinth. Sonorous vibrations are imparted too imperfectly from air to solid bodies, for the propagation of sound to the internal ear to be adequately effected by that means alone; yet already an instance of its being thus propagated has been mentioned. In passing from air directly into water, sonorous vibrations suffer also a considerable diminution of their strength; but if a tense membrane exists between the air and the water, the sonorous vibrations are communicated from the former to the latter medium with very great intensity. This fact, of which Müller gives experimental proof, furnishes at once an explanation of the use of the fenestra rotunda, and of the membrane closing it. They are the means of communicating, in full intensity, the vibrations of the air in the tympanum to the fluid of the labyrinth. This peculiar property of membranes is the result, not of their tenuity alone, but of the elasticity and capability of displacement of their particles; and it is not impaired when, like the membrane of the fenestra rotunda, they are not impregnated with moisture.

Sonorous vibrations are also communicated without any perceptible loss of intensity from the air to the water, when to the membrane forming the medium of communication, there is attached a short, solid body, which occupies the greater part of its surface, and is alone in contact with the water. This fact elucidates the action of the fenestra ovalis, and of the plate of the stapes which occupies it, and, with the preceding fact, shows that both fenestræ—that closed by membrane only, and that with which the movable stapes is connected—transmit very freely the sonorous vibrations from the air to the fluid of the labyrinth.

A small, solid body, fixed in an opening by means of a border of membrane, so as to be movable, communicates sonorous vibrations from air on the one side, to water, or the fluid of the labyrinth, on the other side, much better than solid media not so constructed. But the propagation of sound to the fluid is rendered much more perfect if the solid conductor thus occupying the opening, or fenestra ovalis, is by its other end fixed to the middle of a tense membrane, which has atmospheric air on both sides. A tense membrane is a much better conductor of the vibrations of air than any other solid body bounded by definite surfaces: and the vibrations are also communicated very readily by tense membranes to solid bodies in contact with them. Thus, then, the *membrana tympani* serves for the transmission of sound from the air to the chain of auditory bones. Stretched tightly in its osseous ring, it vibrates with the air in the auditory passage, as any thin tense membrane will, when the air near it is thrown into vibrations by the sounding of a tuning-fork or a musical string. And, from such a tense vibrating membrane, the vibrations are communicated with great intensity to solid bodies which touch it at any point. If, for example, one end of a flat piece of wood be applied to the membrane of a drum, while the other end is held in the hand, vibrations are felt distinctly when the vibrating tuning-fork is held over the membrane without touching it; but the wood alone, isolated from the membrane, will only very feebly propagate the vibrations of the air to the hand.

In comparing the membrana tympani to the membrane of a drum, it is necessary to point out certain important differences.

When a drum is struck, a certain definite tone is elicited (fundamental tone); similarly a drum is thrown into vibration when certain tones are sounded in its neighborhood, while it is quite unaffected by others. In other words, it can only take up and vibrate in response to those tones whose vibrations nearly correspond in number with those of its own fundamental tone. The tympanic membrane can take up an immense range of tones produced by vibrations ranging from 30 to 4000 or 5000 per second. This would be clearly impossible if it were an evenly stretched membrane.

The fact is, that the tympanic membrane is by no means evenly stretched, and this is due partly to its slightly funnel-like form, and partly to its being connected with the chain of auditory ossicles. Further, if the membrane were quite free in its centre, it would go on vibrating as a drum does some time after it is struck, and each sound would be prolonged, leading to considerable confusion. This evil is obviated by the ear-bones, which check the continuance of the vibrations like the "dampers" in a pianoforte.

The *ossicula* of the ear are the better conductors of the sonorous vibrations communicated to them, on account of being isolated by an atmosphere of air, and not continuous with the bones of the cranium; for every solid body thus isolated by a different medium, propagates vibrations with more intensity through its own substance than it communicates them to the surrounding medium, which thus prevents a dispersion of the sound; just as the vibrations of the air in the tubes used for conducting the voice from one apartment to another are prevented from being dispersed by the solid walls of the tube. The vibrations of the membrana tympani are transmitted, therefore, by the chain of ossicula to the fenestra ovalis and fluid of the labyrinth, their dispersion in the tympanum being prevented by the difficulty of the transition of vibrations from solid to gaseous bodies.

The necessity of the presence of air on the inner side of the membrana tympani, in order to enable it and the ossicula auditus to fulfil the objects just described, is obvious. Without this provision, neither would the vibrations of the membrane be free, nor the chain of bones isolated, so as to propagate the sonorous undulations with concentration of their intensity. But while the oscillations of the membrana tympani are readily communicated to the air in the cavity of the tympanum, those of the solid ossicula will not be conducted away by the air, but will be propagated to the labyrinth without being dispersed in the tympanum.

The propagation of sound through the ossicula of the tympanum to the labyrinth, must be effected either by oscillations of the bones, or by a kind of molecular vibration of their particles, or, most probably, by both these kinds of motion.

Movements of the ossicula.—E. Weber has shown that the existence of the membrane over the fenestra rotunda will permit approximation and removal of the stapes to and from the labyrinth. When by the stapes the membrane of the fenestra ovalis is pressed toward the labyrinth, the membrane of the fenestra rotunda may, by the pressure communicated through the fluid of the labyrinth, be pressed toward the cavity of the tympanum.

The long process of the malleus receives the undulations of the membrana tympani (Fig. 364, *a*, *a*) and of the air in a direction indicated by the arrows, nearly perpendicular to itself. From the long process of the malleus they are propagated to its head (*b*): thence into the incus (*c*), the long process of which is parallel with the long process of the malleus. From the long process of the incus the undulations are communicated to the stapes (*d*), which is united to the incus at right angles. The several changes in the direction of the chain of bones have, however, no influence on that of the undulations, which remain the same as it was in the meatus externus and long process of the malleus, so that the undulations are communicated by the stapes to the fenestra ovalis in a perpendicular direction.

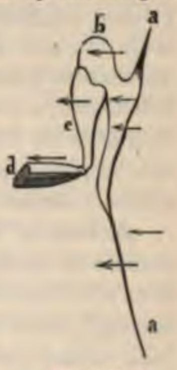


Fig. 364.

Increasing tension of the membrana tympani diminishes the facility of transmission of sonorous undulations from the air to it.

Savart observed that the dry membrana tympani, on the approach of a body emitting a loud sound, rejected particles of sand strewn upon it more strongly when lax than when very tense; and inferred, therefore, that hearing is rendered less acute by increasing the tension of the membrana tympani. Müller has confirmed this by experiments with small membranes arranged so as to imitate the membrana tympani; and it may be confirmed also by observations on one's self.

The pharyngeal orifice of the Eustachian tube is usually shut; during swallowing, however, it is opened; this may be shown as follows:—If the nose and mouth be closed and the cheeks blown out, a sense of pressure is produced in both ears the moment we swallow; this is due, doubtless, to the bulging out of the tympanic membrane by the compressed air which, at that moment, enters the Eustachian tube.

Similarly the tympanic membrane may be pressed in by rarefying the air in the tympanum. This can be readily accomplished by closing the mouth and nose, and making an inspiratory effort and at the same time swallowing (Valsalva). In both cases the sense of hearing is temporarily dulled; proving that equality of pressure on both sides of the tympanic membrane is necessary for its full efficiency.

Functions of Eustachian Tube.—The principal office of the Eustachian tube, in Müller's opinion, has relation to the prevention of these effects of increased tension of the membrana tympani. Its existence and openness will provide for the maintenance of the equilibrium between the air within the tympanum and the external air, so as to prevent the inordinate tension of the membrana tympani which would be produced by too great or too little pressure on either side. While discharging this office, however, it will serve to render sounds clearer, as (Henle suggests) the apertures in violins do; to supply the tympanum with air; and to be an outlet for mucus. If the Eustachian tube were *permanently* open, the sound of one's own voice would probably be greatly intensified, a condition which would of course interfere with the perception of other sounds. At any rate, it is certain that sonorous vibrations can be propagated up the Eustachian tube to the tympanum by means of a tube inserted into the pharyngeal orifice of the Eustachian tube.

Action of Tensor Tympani.—The influence of the tensor tympani muscle in modifying hearing may also be probably explained in connection with the regulation of the tension of the membrana tympani. If, through reflex nervous action, it can be excited to contraction by a very loud sound, just as the iris and orbicularis palpebrarum muscle are by a very intense light, then it is manifest that a very intense sound would, through the action of this muscle, induce a deafening or muffling of the ears. In favor of this supposition we have the fact that a loud sound excites, by reflection, nervous action, winking of the eyelids, and, in persons of irritable nervous system, a sudden contraction of many muscles.

"The ossicula of aquatic mammalia are very bulky and relatively large, especially in the true seals and the sirenia (Manatee and Dugong). In the cetacea the stapes is generally ankylosed to the fenestra ovalis, the malleus is *always* ankylosed to the tympanic bone, yet the membrana tympani is well formed, and there is a manubrium, often ill-developed, but always attached to the membrane by a long process. In the Otariæ or Sealions, where the ossicula are far smaller relatively, and less solid than in whales, manátees, and the earless true seals, there are well-formed, movable external ears. The ossicula seem to be vestigial relics utilized for the auditory function. In land animals they vary in shape according to the type of the animal rather than in relation to its acuteness of hearing. I have never found a muscular laxator tympani in any animal, but the tensor exists as a ligament in whales where the malleus is fixed." (Alban Doran.)

Action of the Stapedius.—The influence of the stapedius muscle in hearing is unknown. It acts upon the stapes in such a manner as to make it rest obliquely in the fenestra ovalis, depressing that side of it on which it acts, and elevating the other side to the same extent. It prevents too great a movement of the bone.

Functions of the Fluid of the Labyrinth.—*The fluid of the labyrinth* is the most general and constant of the acoustic provisions of the labyrinth. In all forms of organs of hearing, the sonorous vibrations affect the auditory nerve through the medium of liquid—the most convenient medium, on many accounts, for such a purpose.

The *crystalline pulverulent masses* (otoliths) in the labryinth would reinforce the sonorous vibrations by their resonance, even if they did not actually touch the membranes upon which the nerves are expanded; but, inasmuch as these bodies lie in contact with the membranous parts of the labyrinth, and the vestibular nerve-fibres are imbedded in them, they communicate to these membranes and the nerves, vibratory impulses of greater intensity than the fluid of the labyrinth can impart. This appears to be their office. Sonorous undulations in water are not perceived by the hand itself immersed in the water, but are felt distinctly through the medium of a rod held in the hand. The fine hair-like prolongations from the epithelial cells of the ampullæ have, probably, the same function.

Functions of the Semicircular Canals.—Besides the function of collecting in their fluid contents sonorous undulations from the bones of the cranium, the semicircular canals appear to have another function less directly connected with the sense of hearing. Experiments show that when the horizontal canal is divided in a pigeon a constant movement of the head from side to side occurs, and similarly, when one of the vertical canals is operated upon, up and down movements of the head are observed. These movements are associated, also, with loss of co-ordination, as after the operation the bird is unable to fly in an orderly manner, but flutters and falls when thrown into the air, and, moreover, is able to feed with difficulty. Hearing remains unimpaired. It has been suggested, therefore, that as loss of co-ordination results from section of these canals, and as co-ordinate muscular movements appear to depend to a considerable extent for their due performance upon a correct notion of our equilibrium, that the semicircular canals are connected in some way with this sense, possibly by the constant alterations of the pressure of the fluid within them; the change in the pressure of the fluid in each canal which takes place on any movement of the head, producing sensations which aid in forming an exact judgment of the alteration of position which has occurred.

Functions of the Cochlea.—The *cochlea* seems to be constructed for the spreading out of the nerve-fibres over a wide extent of surface, upon a solid lamina which communicates with the solid walls of the labyrinth and cranium, at the same time that it is in contact with the fluid of the labyrinth, and which, besides exposing the nerve-fibres to the influence of sonorous undulations, by two media, is itself insulated by fluid on either side.

The connection of the lamina spiralis with the solid walls of the labyrinth, adapts the cochlea for the perception of the sonorous undulations propagated by the solid parts of the head and the walls of the labyrinth. The membranous labyrinth of the vestibule and semicircular canals is suspended free in the perilymph, and is destined more particularly for the perception of sounds through the medium of that fluid, whether the sonorous undulations be imparted to the fluid through the fenestræ, or by the intervention of the cranial bones, as when sounding bodies are brought into communication with the head or teeth. The spiral lamina on which the nervous fibres are expanded in the cochlea, is, on the contrary, continuous with the solid walls of the labyrinth, and receives directly from them the impulses which they transmit. This is an important advantage; for the impulses imparted by solid bodies have, *cæteris paribus*, a greater absolute intensity than those communicated by water. And, even when a sound is excited in the water, the sonorous undulations are more intense in the water near the surface of the vessel containing it, than in other parts of the water equally distant from the point of origin of the sound; thus we may conclude that, *cæteris paribus*, the sonorous undulations of solid bodies act with greater intensity than those of water. Hence, we perceive at once an important use of the cochlea.

This is not, however, the sole office of the cochlea; the spiral lamina, as well as the membranous labyrinth, receives sonorous impulses through the medium of the fluid of the labyrinth from the cavity of the vestibule, and from the fenestra rotunda. The lamina spiralis is, indeed, much better calculated to render the action of these undulations upon the auditory nerve efficient, than the membranous labyrinth is; for as a solid body insulated by a different medium, it is capable of resonance.

The *rods of Corti* are probably arranged so that each is set to vibrate in unison with a particular tone, and thus strike a particular note, the sensation of which is carried to the brain by those filaments of the auditory nerve with which the little vibrating rod is connected. The distinctive function, therefore, of these minute bodies is, probably, to render sensible to the brain the various musical notes and tones, one of them answering to one tone, and one to another; while perhaps the other parts of the organ of hearing discriminate between the intensities of different sounds, rather than their qualities.

"In the cochlea we have to do with a series of apparatus adapted for performing sympathetic vibrations with wonderful exactness. We have here before us a musical instrument which is designed, not to create musical sounds, but to render them perceptible, and which is similar in construction to artificial musical instruments, but which far surpasses them in the delicacy as well as the simplicity of its execution. For, while in a piano every string must have a separate hammer by means of which it is sounded, the ear possesses a single hammer of an ingenious form in its ear-bones, which can make every string of the organ of Corti sound separately." (Bernstein.)

About 3000 rods of Corti are present in the human ear; this would give about 400 to each of the seven octaves which are within the compass of the ear. Thus about 32 would go to each semi-*tone*. Weber asserts that accomplished musicians can appreciate differences in pitch as small as $\frac{1}{64}$th of a tone. Thus on the theory above advanced, the delicacy of discrimination would, in this case, appear to have reached its limits.

Sensibility of the Auditory Nerve.—Any elastic body, *e.g.*, air, a membrane, or a string performing a certain number of regular vibrations in the second, gives rise to what is termed a musical sound or *tone*. We must, however, distinguish between a musical sound and a mere noise; the latter being due to irregular vibrations.

Qualities of Musical Sound.—Musical sounds are distinguished from each other by three qualities. 1. *Strength* or intensity, which is due to the amplitude or length of the vibrations. 2. *Pitch*, which depends upon the number of vibrations in a second. 3. *Quality, Color*, or *Timbre*. It is by this property that we distinguish the same note sounded on two instruments, *e.g.*, a piano and a flute. It has been proved by Helmholtz to depend on the number of secondary notes, termed *harmonics*, which are present with the predominating or fundamental tone.

It would appear that two impulses, which are equivalent to four single or half vibrations, are sufficient to produce a definite note, audible as such through the auditory nerve. The note produced by the shocks of the teeth of a revolving wheel, at regular intervals upon a solid body, is still heard when the teeth of the wheel are removed in succession, until two only are left; the second produced by the impulse of these two teeth has still the same definite value in the scale of music.

The maximum and minimum of the intervals of successive impulses still appreciable through the auditory nerve as determinate sounds, have been determined by M. Savart. If their intensity is sufficiently great, sounds are still audible which result from the succession of 48,000 half vibrations, or 24,000 impulses in a second; and this, probably, is not the extreme limit in acuteness of sounds perceptible by the ear. For the opposite extreme, he has succeeded in rendering sounds audible which were produced by only fourteen or eighteen half vibrations, or seven or eight impulses in a second; and sounds still deeper might probably be heard, if the individual impulses could be sufficiently prolonged.

By removing one or several teeth from the toothed wheel the fact has been demonstrated that in the case of the auditory nerve, as in that of the optic nerve, the sensation continues longer than the impression which causes it; for a removal of a tooth from the wheel produced no interruption of the sound. The gradual cessation of the sensation of sound renders it difficult, however, to determine its exact duration beyond that of the impression of the sonorous impulses.

Direction of Sounds.—The power of perceiving the *direction of sounds* is not a faculty of the sense of hearing itself, but is an act of the mind judging on experience previously acquired. From the modifications which the sensation of sound undergoes according to the direction in which the sound reaches us, the mind infers the position of the sounding body. The only true guide for this inference is the more intense action of the sound upon one than upon the other ear. But even here there is room for much deception, by the influence of reflexion or resonance, and by the propagation of sound from a distance, without loss of intensity, through curved conducting tubes filled with air. By means of such tubes, or of solid conductors, which convey the sonorous vibrations from their source to a distant resonant body, sounds may be made to appear to originate in a new situation. The direction of sound may also be judged of by means of one ear only; the position of the ear and head being varied, so that the sonorous undulations at one moment fall upon the ear in a perpendicular direction, at another moment obliquely. But when neither of these circumstances can guide us in distinguishing the direction of sound, as when it falls equally upon both ears, its source being, for example, either directly in front or behind us, it becomes impossible to determine whence the sound comes.

Distance of Sounds.—The *distance of the source of sounds* is not recognized by the sense itself, but is inferred from their intensity. The sound itself is always seated but in one place, namely, in our ear; but it is interpreted as coming from an exterior soniferous body. When the intensity of the voice is modified in imitation of the effect of distance, it excites the idea of its originating at a distance. Ventriloquists take advantage of the difficulty with which the direction of sound is recognized, and also the influence of the imagination over our judgment, when they direct their voice in a certain direction, and at the same time pretend, themselves, to hear the sounds as coming from thence.

The effect of the action of sonorous undulations upon the nerve of hearing, endures somewhat longer than the period during which the undulations are passing through the ear. If, however, the impressions of the same sound be very long continued, or constantly repeated for a long time, then the sensation produced may continue for a very long time, more than twelve or twenty-four hours even, after the original cause of the sound has ceased.

Binaural Sensations.—Corresponding to the double vision of the same object with the two eyes, is the double hearing with the two ears; and analogous to the double vision with one eye, dependent on unequal refraction, is the double hearing of a single sound with one ear, owing to the sound coming to the ear through media of unequal conducting power. The first kind of double hearing is very rare; instances of it are recorded, however, by Sauvages and Itard. The second kind, which depends on the unequal conducting power of two media through which the same sound is transmitted to the ear, may easily be experienced. If a small bell be sounded in water, while the ears are closed by plugs, and a solid conductor be interposed between the water and the ear, two sounds will be heard differing in intensity and tone; one being conveyed to the ear through the medium of the atmosphere, the other through the conducting-rod.

Subjective Sensations of Sound.—*Subjective sounds* are the result of a state of irritation or excitement of the auditory nerve produced by other causes than sonorous impulses. A state of excitement of this nerve, however induced, gives rise to the sensation of sound. Hence the ringing and buzzing in the ears heard by persons of irritable and exhausted nervous system, and by patients with cerebral disease, or disease of the auditory nerve itself; hence also the noise in the ears heard for some time after a long journey in a rattling noisy vehicle. Ritter found that electricity also excites a sound in the ears. From the above truly subjective sound we must distinguish those dependent, not on a state of the auditory nerve itself merely, but on sonorous vibrations excited in the auditory apparatus. Such are the buzzing sounds attendant on vascular congestion of the head and ear, or on aneurismal dilatation of the vessels. Frequently even the simple pulsatory circulation of the blood in the ear is heard. To the sounds of this class belong also the buzz or hum heard during the contraction of the palatine muscles in the act of yawning; during the forcing of air into the tympanum, so as to make tense the membrana tympani; and in the act of blowing the nose, as well as during the forcible depression of the lower jaw.

Irritation or excitement of the auditory nerve is capable of giving rise to movements in the body, and to sensations in other organs of sense. In both cases it is probable that the laws of reflex action, through the medium of the brain, came into play. An intense and sudden noise excites, in every person, closure of the eyelids, and, in nervous individuals, a start of the whole body or an unpleasant sensation, like that produced by an electric shock, throughout the body, and sometimes a particular feeling in the external ear. Various sounds cause in many people a disagreeable feeling in the teeth, or a sensation of cold tickling through the body, and, in some people, intense sounds are said to make the saliva collect.

SIGHT.

Eyelids and Lachrymal Apparatus.—The *eyelids* consist of two movable folds of skin, each of which is kept in shape by a thin plate of yellow elastic tissue. Along their free edges are inserted a number of curved hairs (*eyelashes*), which, when the lids are half closed, serve to protect the eye from dust and other foreign bodies: their tactile sensibility is also very delicate.

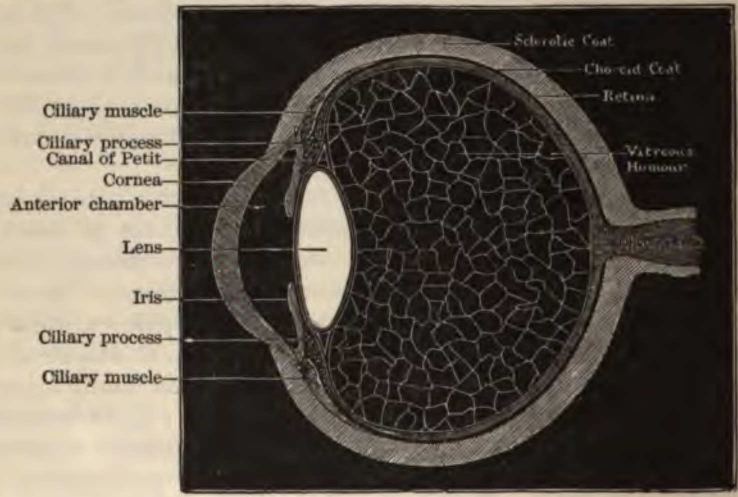


FIG. 365.

On the inner surface of the elastic tissue are disposed a number of small racemose glands (Meibomian), whose ducts open near the free edge of the lid.

The orbital surface of each lid is lined by a delicate, highly sensitive mucous membrane (*conjunctiva*), which is continuous with the skin at the free edge of each lid, and after lining the inner surface of the eyelid is reflected on to the eyeball, being somewhat loosely adherent to the sclerotic coat. The epithelial layer is continued over the cornea at its anterior epithelium. At the inner edge of the eye the conjunctiva becomes continuous with the mucous lining of the lachrymal sac and duct, which again is continuous with the mucous membrane of the inferior meatus of the nose.

The *lachrymal gland* is lodged in the upper and outer angle of the orbit. Its secretion, which issues from several ducts on the inner surface of the upper lid, under ordinary circumstances just suffices to keep the conjunctiva moist. It passes out through two small openings (puncta lachrymalia) near the inner angle of the eye, one in each lid, into the lachrymal sac, and thence along the nasal duct into the inferior meatus of the nose. The excessive secretion poured out under the influence of any irritating vapor or painful emotion overflows the lower lid in the form of tears.

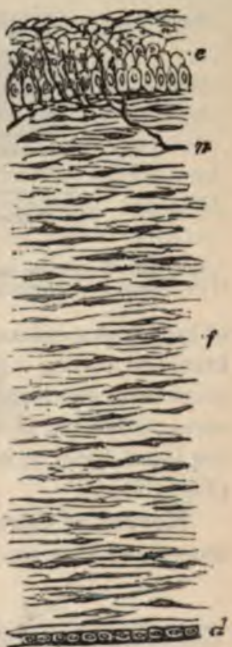


FIG. 366.—Vertical section of rabbit's cornea, stained with gold chloride. *e*, Laminated anterior epithelium. Immediately beneath this is the anterior elastic lamina of Bowman. *n*, Nerves forming a delicate sub-epithelial plexus, and sending up fine twigs between the epithelial cells to end in a second plexus on the free surface; *d*, Descemet's membrane, consisting of a fine elastic layer, and a single layer of epithelial cells; the substance of the cornea, *f*, is seen to be fibrillated, and contains many layers of branched corpuscles, arranged parallel to the free surface, and here seen edgewise. (Schofield.)

The eyelids are closed by the contraction of a sphincter muscle (*orbicularis*), supplied by the Facial nerve; the upper lid is raised by the *Levator palpebræ superioris*, which is supplied by the Third nerve.

THE EYEBALL.

The eyeball or the organ of vision (Fig. 365) consists of a variety of structures which may be thus enumerated:—

The *sclerotic*, or outermost coat, envelopes about five-sixths of the eyeball: continuous with it, in front, and occupying the remaining sixth, is the *cornea*. Immediately within the sclerotic is the *choroid* coat, and within the choroid is the *retina*. The interior of the eyeball is well-nigh filled by the *aqueous* and *vitreous humors* and the *crystalline lens;* but, also, there is suspended in the interior a contractile and perforated curtain,—the *iris*, for regulating the admission of light, and behind the junction of the sclerotic and cornea is a ciliary muscle, the function of which is to adapt the eye for seeing objects at various distances.

Structure of Sclerotic.—The *sclerotic* coat is composed of connective tissue, arranged in variously disposed and inter-communicating layers. It is strong, tough, and opaque, and not very elastic.

Structure of Cornea.—The *cornea* is a transparent membrane which forms a segment of a smaller sphere than the rest of the eyeball, and is let in, as it were, into the sclerotic with which it is continuous all round. It is coated with a laminated anterior epithelium (*a*, Fig. 367) consisting of seven or eight layers of cells, of which the superficial ones are flattened and scaly, and the deeper ones more or less columnar. Immediately beneath this is the anterior elastic lamina (Bowman).

The cornea tissue proper as well as its epithelium is, in the adult, completely destitute of blood-vessels; it consists of an intercellular ground-substance of rather obscurely fibrillated flattened bundles of connective tissue, arranged parallel to the free surface, and forming the boundaries of branched anastomosing spaces in which the cornea-corpuscles lie. These branched cornea-corpuscles have been seen to creep by amœboid movement from one branched space into another. At its posterior surface the cornea is limited by the posterior elastic lamina, or membrane of Descemet, the inner layer of which consists of a single stratum of epithelial cells (Fig. 366, *d*).

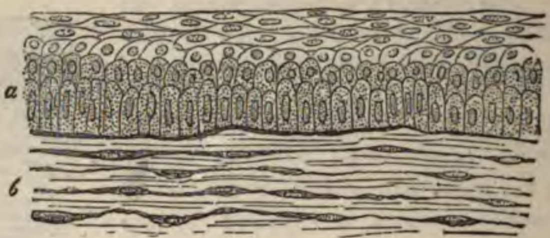


FIG. 367.—Vertical section of rabbit's cornea. *a*, Anterior epithelium, showing the different shapes of the cells at various depths from the free surface; *b*, portion of the substance of cornea. (Klein.)

Nerves of Cornea.—The nerves of the cornea are both large and numerous: they are derived from the ciliary nerves. They traverse the substance of the cornea, in which some of them terminate, in the direction of its anterior surface, near which the axis cylinders break up into bundles of very delicate beaded fibrillæ (Fig. 366): these form a plexus immediately beneath the epithelium, from which delicate fibrils pass up

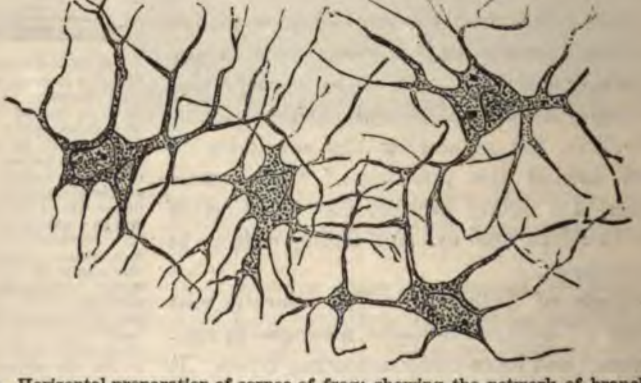


FIG. 368.—Horizontal preparation of cornea of frog; showing the network of branched cornea corpuscles. The ground substance is completely colorless. × 400. (Klein.)

between the cells anastomosing with horizontal branches, and forming a deep intra-epithelial plexus, from which fibres ascend, till near the surface they form a superficial intra-epithelial network.

Structure of Choroid (*tunica vasculosa*).—This coat of the eyeball is formed by a very rich network of capillaries (chorio-capillaris) outside which again are connective-tissue layers of stellate pigmented cells (Fig. 25) with numerous arteries and veins.

The choroid coat ends in front in what are called the *ciliary processes* (Fig. 365).

Structure of Retina.—The *retina* (Fig. 370) is a delicate membrane, concave, with the concavity directed forward and ending in front, near the outer part of the ciliary processes in a finely notched edge,—the *ora serrata*. Semi-transparent when fresh, it soon becomes clouded and opaque, with a pinkish tint from the blood in its minute vessels. It results from the sudden spreading out or expansion of the optic nerve, of whose terminal fibres, apparently deprived of their external white substance, together with nerve cells, it is essentially composed.

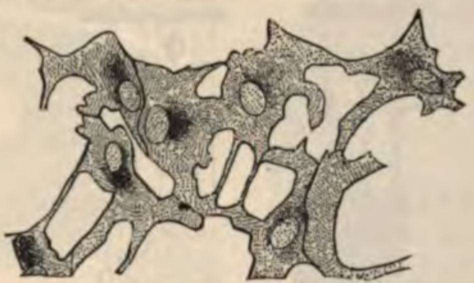


FIG. 369.—Surface view of part of lamella of kitten's cornea, prepared first with caustic potash and then with nitrate of silver. (By this method the branched cornea-corpuscles with their granular protoplasm and large oval nuclei are brought out.) × 450. (Klein and Noble Smith.)

Exactly in the centre of the retina, and at a point thus corresponding to the axis of the eye in which the sense of vision is most perfect, is a round yellowish elevated spot, about $\frac{1}{24}$ of an inch in diameter, having a minute aperture at its summit, and called after its discoverer the *yellow spot of Sœmmering*. In its centre is a minute depression called *fovea centralis*. About $\frac{1}{10}$ of an inch to the inner side of the yellow spot, and consequently of the axis of the eye, is the point at which the optic nerve begins to spread out its fibres to form the retina. This is the only point of the surface of the retina from which the power of vision is absent.

The retina consists of certain nervous elements arranged in several layers, and supported by a very delicate connective tissue.

From the nature of the case there is considerable uncertainty as to the character (nervous or connective tissue) of some of the layers of the retina. The following ten layers, from within outward, are usually to be distinguished in a vertical section (Figs. 370, 373).

1. *Membrana limitans interna:* a delicate membrane in contact with the vitreous humor.

2. *Fibres of optic nerve.* This layer is of very varying thickness in different parts of the retina: it consists chiefly of non-medullated fibres which interlace, and some of which are continuous with processes of the large nerve-cells forming the next layer.

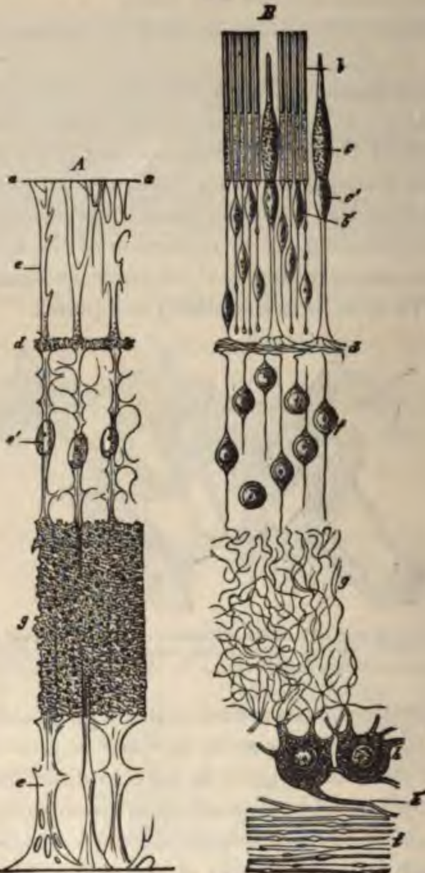


FIG. 370.—Diagram of the retina. A, connective tissue portion; B, nervous portion (*the two must be combined to form the complete retina*); *a a*, membrana limitans externa; *b*, rods; *c*, cones; *b'*, rod-granule; *c'*, cone-granule; both belonging to the external granule layer: *e*, Müller's sustentacular fibres, with their nuclei *e'*; *d*, intergranular layer; *f*, internal granule layer; *g*, molecular layer, connective-tissue portion; *g'*, molecular layer, nerve fibril portion; *h*, ganglion cells; *h'*, their axis-cylinder process; *i*, nerve-fibre layer. (Max Schultze.)

3. *Layer of ganglionic corpuscles,* consisting of large multipolar nerve-cells, sometimes forming a single layer. In some parts of the retina, especially near the *macula lutea,* this layer is very thick, consisting of several distinct strata of nerve-cells. These cells lie in the spaces of a connective-tissue framework.

4. *Molecular layer.* This presents a finely granulated appearance. It consists of a punctiform connective-tissue traversed by numberless very fine fibrillar processes of the nerve-cells.

5. *Internal granular layer.* This consists chiefly of numerous small round cells with a very small quantity of protoplasm surrounding a large nucleus; they are generally bipolar, giving off one process outward and another inward. They greatly resemble the ganglionic corpuscles of the cerebellum (Fig. 330). Besides these there are large oval nuclei (*é*, Fig. 370, A) belonging to the sustentacular connective-tissue fibres.

6. *Intergranular layer;* which closely resembles the molecular layer, but is much thinner. It consists of finely-dotted connective tissue with nerve fibrils.

7. *External granular layer;* which consists of several strata of small cells resembling those of the internal granular layer; they have been classed as rod and cone granules, according as they are connected by very delicate fibrils with the rods and cones respectively. They are lodged in the meshes of a connective-tissue framework. Both the internal and external granular layer stain very rapidly and deeply with hæmatoxylin, while the rod and cone layer remains quite unstained.

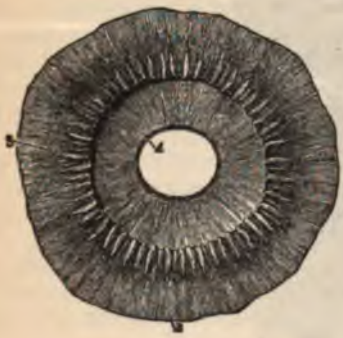


FIG. 371.

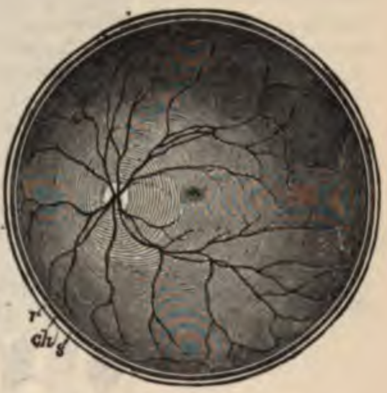


FIG. 372.

FIG. 371.—Ciliary processes, as seen from behind. 1, posterior surface of the iris, with the sphincter muscle of the pupil; 2, anterior part of the choroid coat; 3, one of the ciliary processes, of which about seventy are represented. ½.

FIG. 372.—The posterior half of the retina of the left eye, viewed from before; *s*, the cut edge of the sclerotic coat; *ch*, the choroid; *r*, the retina; in the interior at the middle, the macula lutea with the depression of the fovea centralis is represented by a slight oval shade; toward the left side the light spot indicates the colliculus or eminence at the entrance of the optic nerve, from the centre of which the arteria centralis is seen spreading its branches into the retina, leaving the part occupied by the macula comparatively free. (After Henle.)

8. *Membrana limitans externa;* a delicate, well-defined membrane, clearly marking the internal limit of the rod and cone layer

9. *Rod and cone layer, bacillar layer, or membrane of Jacob,* consisting of two kinds of elements: the "rods," which are cylindrical and of uniform diameter throughout, and the "cones," whose internal portion is

distinctly conical, and surmounted externally by a thin rod-like body. According to the researches of Max Schultze, the rods show traces of longitudinal fibrillation, and, moreover, have a great tendency to break up into a number of transverse discs like a pile of coins.

In the rod and cone layer of birds, the cones usually predominate largely in number, whereas in man the rods are by far the more numerous. In nocturnal birds, however, such as the owl, only rods are present, and the same appears to be the case in many nocturnal and burrowing mammalia, *e.g.*, bat, hedge-hog, mouse, and mole.

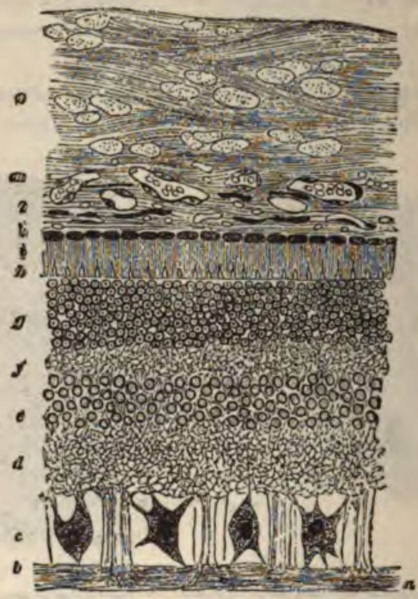


FIG. 373.—Section of the retina, choroid, and part of the sclerotic, moderately magnified. *a*, membrana limitans interna; *b*, nerve-fibre layer traversed by Müller's sustentacular fibres (of the connective tissue system); *c*, ganglion-cell layer; *d*, molecular layer; *e*, internal granular layer; *f*, intergranular layer; *g*, external granular layer; *h*, membrana limitans externa, running along the lower part of *i*, the layer of rods and cones; *k*, pigment cell layer formerly described as part of the choroid; *l*, *m*, internal and external vascular portions of the choroid, the first containing capillaries, the second larger blood-vessels, cut in transverse section; *n*, sclerotic. (W. Pye.)

10. *Pigment cell layer*, which was formerly considered part of the choroid.

In the centre of the yellow spot (macula lutea), all the layers of the retina become greatly thinned out and almost disappear, except the rod and cone layer, which considerably increases in thickness, and comes to consists almost entirely of long slender cones, the rods being very few in number, or entirely absent. There are capillaries here, but none of the larger branches of the retinal arteries.

With regard to the connection of the various layers there is still some uncertainty. Fig. 370 represents the view of Max Schultze. According to this there are certain sustentacular fibres of connective tissue (radiating fibres of Müller) which spring from the *membranal imitans interna* almost vertically, and traverse the retina to the *limitans externa,* whence very delicate connective tissue processes pass up between the rods and cones. The framework which they form is represented in Fig. 370, A. The *nervous* elements of the retina are represented in Fig. 370, B, and consist of delicate fibres passing up from the nerve-fibre layer to the rods and cones, and connected with the ganglionic corpuscles and granules of the internal and external layer.

Blood-vessels of the Eyeball.—The eye is very richly supplied with blood-vessels. In addition to the conjunctival vessels which are derived from the palpebral and lachrymal arteries, there are at least two other distinct sets of vessels supplying the tunics of the eyeball. (1) The vessels of the sclerotic, choroid, and iris, and (2) The vessels of the retina.

(1.) These are the short and long *posterior* ciliary arteries which pierce the sclerotic in the posterior half of the eyeball, and the *anterior* ciliary which enter near the insertions of the recti. These vessels anastomose and form a very rich choroidal plexus; they also supply the iris and ciliary processes, forming a very highly vascular circle round the outer margin of the iris and adjoining portion of the sclerotic.

The distinctness of these vessels from those of the conjunctiva is well seen in the difference between the bright red of blood-shot eyes (conjunctival congestion), and the pink zone surrounding the cornea which indicates deep-seated ciliary congestion.

(2.) The *retinal vessels* (Fig. 372) are derived from the *arteria centralis retinæ,* which enters the eyeball along the centre of the optic nerve. They ramify all over the retina, chiefly in its inner layers. They can be seen by direct ophthalmoscopic examination.

OPTICAL APPARATUS.

The eye may be compared to the *camera* used by photographers formed by a convex lens. In this instrument images of external objects are thrown upon a ground-glass screen at the back of a box, the interior of which is painted black. In the eye the convex lens is represented by the crystalline lens, the dark box by the eyeball with its choroidal pigment, and the screen by the retina. In the case of the camera the screen is enabled to receive clear images of objects at different distances, by being shifted forward and back: while the convex lens too can be screwed in and out. The corresponding contrivance in the eye will be described under the head of *Accommodation.*

Conditions Necessary.—The essential constituents of the optical apparatus of the eye may be thus enumerated: (1) A *nervous* structure (the retina) to be stimulated by light and to transmit by means of the optic nerve, of which it is the terminal expansion, the impression of the stimulation to the brain, in which it excites the sensation of vision; (2)

An *apparatus* consisting of certain refractory media, cornea, crystalline lens, aqueous and vitreous humor, the function of which is to collect together into one point the different divergent rays emitted by each point of every external body and of giving them such directions that they are exactly focussed upon the retina, and thus produce an exact image of the object from which they proceed. For as light radiates from a luminous body in all directions, when the media offer no impediment to its transmission, a luminous point will necessarily illuminate all parts of a surface, such as the retina opposed to it, and not merely one single point. A retina, therefore, without any optical apparatus placed in front of it to separate the light of different objects, would not allow of distinct vision, but would merely transmit such a general impression of daylight as would distinguish it from the night; (3) A contractile *diaphragm* (iris) with a central aperture for regulating the quantity of light admitted into the eye; and (4) a contractile structure (ciliary muscle), an arrangement by which the chief refracting medium (crystalline lens) shall be so controlled as to enable objects to be seen at various distances, causing convergence of the rays of light that fall upon and traverse it (accommodation).

REFRACTING MEDIA.

Of the refracting media the *cornea* is in a twofold manner capable of refracting and causing convergence of the rays of light that fall upon and traverse it. It thus affects them first, by its density; for it is a law in optics that when rays of light pass from a rarer into a denser medium, if they impinge upon the surface in a direction removed from the perpendicular, they are bent out of their former direction toward that of a line perpendicular to the surface of the denser medium; and, secondly, by its convexity; since rays of light impinging upon a convex transparent surface, are refracted toward the centre, those being most refracted which are farthest from the centre of the convex surface.

Behind the cornea is a space containing a thin watery fluid, the *aqueous humor*, holding in solution a small quantity of sodium chloride and extractive matter. The space containing the aqueous humor is divided into an anterior and posterior *chamber* by a membranous partition, *the iris*, to be presently again mentioned. The effect produced by the aqueous humor on the rays of light traversing it, is not yet fully ascertained. Its chief use, probably, is to assist in filling the eyeball, so as to maintain its proper convexity, and at the same time to furnish a medium in which the movements of the iris can take place.

Behind the aqueous humor and the iris, and imbedded in the anterior part of the medium next to be described, viz., the vitreous humor, is seated a doubly-convex body, the *crystalline lens*, which is the most important refracting structure of the eye. The structure of the lens is very complex. It consists essentially of fibres united side by side to each other, and arranged together in very numerous laminæ, which are so placed upon one another, that when hardened in spirit the lens splits into three portions in the form of sectors, each of which is composed of superimposed concentric laminæ. The lens increases in density and, consequently, in power of refraction, from without inward; the central part, usually termed the nucleus, being the most dense.

The *vitreous humor* constitutes nearly four-fifths of the whole globe of the eye. It fills up the space between the retina and the lens, and its soft jelly-like substance consists essentially of numerous layers, formed of delicate, simple membrane, the spaces between which are filled with a watery, pellucid fluid. Its principal use appears to be that of giving the proper distension to the globe of the eye, and of keeping the surface of the retina at a proper distance from the lens.

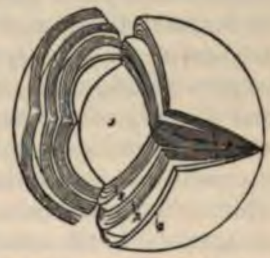


FIG. 374.—Laminated structure of the crystalline lens. The laminæ are split up after hardening in alcohol. 1, the denser central part or nucleus; 2, the successive external layers. $\frac{4}{1}$. (Arnold.)

Action of the Iris.—The *iris* is a vertically-placed membranous diaphragm, provided with a central aperture, the *pupil*, for the transmission of light. It is composed of plain muscular fibres imbedded in ordinary fibro-cellular or connective tissue. The muscular fibres have a direction, for the most part, radiating from the circumference toward the pupil; but as they approach the pupillary margin, they assume a circular direction, and at the very edge form a complete ring. By the contraction of the radiating fibres (dilator pupillæ) the size of the pupil is enlarged: by the contraction of the circular ones (sphincter pupillæ), it is diminished. The object effected by the movements of the iris, is the regulation of the quantity of light transmitted to the retina. The posterior surface of the iris is coated with a layer of dark pigment, so that no rays of light can pass to the retina, except such as are admitted through the aperture of the pupil.

This iris is very richly supplied with nerves and blood-vessels. Its circular muscular fibres are supplied by the third (by the short ciliary branches of the ophthalmic ganglion), and its radiating fibres, by the sympathetic and fifth cranial nerve (by the long ciliary branches of the nasal nerve).

Contraction of the pupil occurs under the following circumstances: (1) On exposure of the eye to a bright light; (2) when the eye is focussed for near objects; (3) when the eyes converge to look at a near object; (4) on the local application of eserine (active principle of Calabar bean); (5) on the administration internally of opium, aconite, and in the early stages of chloroform and alcohol poisoning; (6) on division of the cervical sympathetic or stimulation of the third nerve. *Dilatation* of the pupil occurs (1) in a dim light; (2) when the eye is focussed for distant objects; (3) on the local application of atropine and its allied alkaloids; (4) on the internal administration of atropine and its allies; (5) in the later stages of poisoning by chloroform, opium, and other drugs; (6) on paralysis of the third nerve; (7) on stimulation of the cervical sympathetic, or of its centre in the floor of the front of the aqueduct of Sylvius. The contraction of the pupil appears to be under the control of a centre in the corpora quadrigemina, and this is reflexly stimulated by a bright light, and the dilatation when the reflex centre is not in action is due to the more powerful sympathetic action; but in addition, it appears that both contraction and dilatation may be produced by a local mechanism, upon which certain drugs can act, which is independent of and probably often antagonistic to the action of the central apparatus of the third and sympathetic nerves. The action of the fifth nerve upon the pupil is not well understood, but its apparent effect in producing dilatation is due to the mixture of sympathetic fibres with its nasal branch. The sympathetic influence upon the radiating fibres is believed to be conveyed, not by the long ciliary branches of that nerve, but by the short ciliary branches from the ophthalmic ganglion.

The close sympathy subsisting between the two eyes is nowhere better shown than by the condition of the pupil. If one eye be shaded by the hand its pupil will of course dilate; but the pupil of the *other* eye will also dilate, though it is unshaded.

Ciliary Muscle.—The *ciliary muscle* is composed of plain muscular fibres, which form a narrow zone around the interior of the eyeball, near the line of junction of the cornea with the sclerotic, and just behind the outer border of the iris (Fig. 365). The *outermost* fibres of this muscle are attached in front to the inner part of the sclerotic and cornea at their line of junction, and diverging somewhat, are fixed to the ciliary processes, and a small portion of the choroid immediately behind them. The *inner* fibres immediately within the preceding, form a circular zone around the interior of the eyeball, outside the ciliary processes. They compose the ring formerly called the ciliary ligament.

Accommodation of the Eye.—The distinctness of the image formed upon the retina, is mainly dependent on the rays emitted by each luminous point of the object being brought to a perfect focus upon the retina. If this focus occur at a point either in front of, or behind the retina, indistinctness of vision ensues, with the production of a halo. The *focal distance, i.e.*, the distance of the point at which the luminous rays from a lens are collected, besides being regulated by the degree of convexity and density of the lens, varies with the distance of the object from the lens, being greater as this is shorter, and *vice versâ*. Hence, since objects placed at various distances from the eye can, within a certain range, different in different persons, be seen with almost equal distinctness, there must be some provision by which the eye is enabled to adapt itself, so that whatever length the focal distance may be, the focal point may always fall exactly upon the retina.

This power of *adaptation of the eye to vision at different distances* has received the most varied explanations. It is obvious that the effect might be produced in either of two ways, viz., by altering the convexity or intensity, and thus the refracting power, either of the cornea or lens; or by changing the position either of the retina or of the lens, so that whether the object viewed be near or distant, and the focal distance thus increased or diminished, the focal point to which the rays are converged by the lens may always be at the place occupied by the retina. The amount of either of these changes required in even the widest range of vision, is extremely small. For, from the refractive powers of the media of the eye, it has been calculated by Olbers, that the difference between the focal distances of the images of an object at such a distance that the rays are parallel, and of one at the distance of four inches, is only about 0·143 of an inch. On this calculation, the change in the distance of the retina from the lens required for vision at all distances, supposing the cornea and lens to maintain the same form, would not be more than about one line.

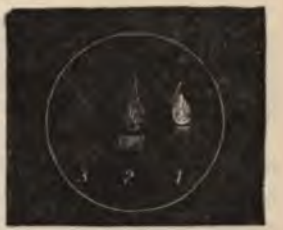


FIG. 375.—Diagram showing three reflections of a candle. 1, From the anterior surface of cornea: 2, from the anterior surface of lens; 3, from the posterior surface of lens. For further explanation, see text. The experiment is best performed by employing an instrument invented by Helmholtz, termed a *Phakoscope*.

It is now almost universally believed that Helmholtz is right in his statement that the immediate cause of the adaptation of the eye for objects at different distances is a varying shape of the lens, its front surface becoming more or less convex, according to the distance of the object looked at. The nearer the object, the more convex does the front surface of the lens become, and *vice versâ;* the back surface taking little or no share in the production of the effect required. The following simple experiment illustrates this point. If a small flame be held a little to one side of a person's eye, an observer looking at the eye from the other side sees three distinct images of the flame (Fig. 375). The first and brightest is (1) a small erect image formed by the anterior convex surface of the cornea: the second (2) is also erect, but larger and less distinct than the preceding, and is formed at the anterior convex surface of the lens: the third (3) is smaller and reversed, it is formed at the posterior surface of the lens, which is concave forward, and therefore, like all concave mirrors, gives a reversed image. If now the eye under observation be made to look at a near object, the second image becomes smaller, clearer, and approaches the first. If the eye be now adjusted for a far point, the second image enlarges again, becomes less distinct, and recedes from the first. In both cases alike the first and third images remain unaltered in size and relative position. This proves that during accommodation for near objects the curvature of the cornea, and of the *posterior* of the lens, remains unaltered, while the *anterior* surface of the lens becomes more convex and approaches the cornea.

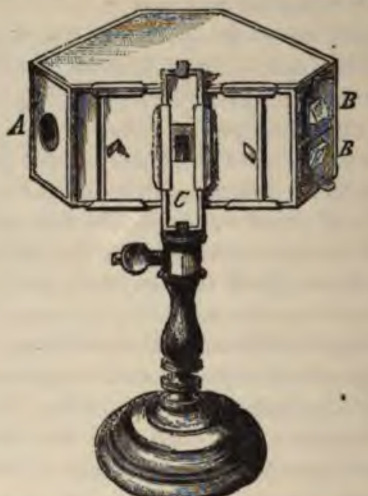


FIG. 376.—Phakoscope of Helmholtz. At *B B′* are two prisms, by which the light of a candle is concentrated on the eye of the person experimented with at *C*; *A* is the aperture for the eye of the observer. The observer notices three double images, as in Fig. 375, reflected from the eye under examination when the eye is fixed upon a distant object: the position of the images having been noticed, the eye is then made to focus a near object, such as a needle pushed up by *C*; the images from the anterior surface of the lens will be observed to move toward each other, in consequence of the lens becoming more convex.

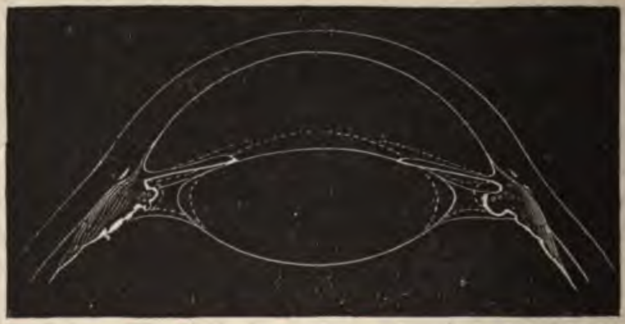


FIG. 377.—Diagram representing by dotted lines the alteration in the shape of the lens, on accommodation for near objects. (E. Landolt.)

Mechanism of Accommodation.—Of course the lens has no inherent power of contraction, and therefore its changes of outline must be produced by some power from without; and there seems no reason to doubt that this power is supplied by the ciliary muscle. It is sometimes termed the *tensor choroideæ*. As this name implies, from its attachment (p. 206, Vol. II.), it is able to draw forward the choroid, and therefore slackens the tension of the suspensory ligament of the lens which arises from it. The lens is usually partly flattened by the action of the suspensory ligament; and the ciliary muscle by diminishing the tension of this ligament diminishes, to a proportional degree, the flattening of which it is the cause. On diminution or cessation of the action of the ciliary muscle, the lens returns, in a corresponding degree, to its former shape, by virtue of the elasticity of its suspensory ligament (Fig. 377). From this it will appear that the eye is usually focussed for distant objects. In viewing near objects the pupil contracts, the opposite effect taking place on withdrawal of the attention from near objects, and fixing it on those distant.

Range of Distinct Vision. Near-point.—In every eye there is a limit to the power of accommodation. If a book be brought nearer and nearer to the eye, the type at last becomes indistinct and cannot be brought into focus by any effort of accommodation, however strong. This, which is termed the *near-point*, can be determined by the following experiment (*Scheiner*). Two small holes are pricked in a card with a pin not more than a line apart, at any rate their distance from each other must not exceed the diameter of the pupil. The card is held close in front of the eye, and a small needle viewed through the pin-holes. At a moderate distance it can be clearly focussed, but when brought nearer, beyond a certain point, the image appears double or at any rate blurred. This point where the needle ceases to appear single is the near-point. Its distance from the eye can of course be readily measured. It is usually about 5 or 6 inches. In the accompanying figure (Fig. 378) the lens *b* represents the eye; *ef* the two pinholes in the card, *nn* the retina; *a* represents the position of the needle. When the needle is at a moderate distance, the two pencils of light coming from *e* and *f*, are focussed at a single point on the retina *nn*. If the needle be brought nearer than the near-point, the strongest effort of accommodation is not sufficient to focus the two pencils, they meet at a point behind the retina. The effect is

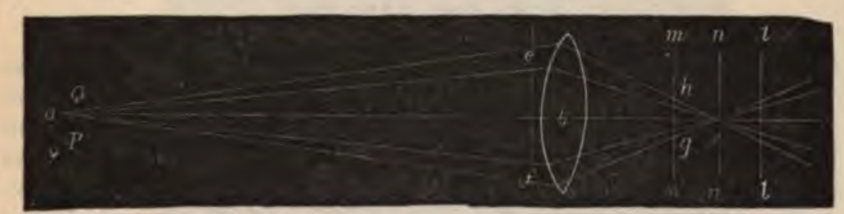


Fig. 378.—Diagram of experiment to ascertain the minimum distance of distinct vision.

the same as if the retina were shifted forward to *mm*. Two images, *h*, *g*, are formed, one from each hole. It is interesting to note that when two images are produced, the lower one *g* really appears in the position Q, while the upper one appears in the position P. This may be readily verified by covering the holes in succession.

The contents of the ball of the eye are surrounded and kept in position by the *cornea*, and the dense, fibrous membrane before referred to as the *sclerotic*, which, besides thus encasing the contents of the eye, serves to give attachment to the various muscles by which the movements of the eyeball are effected. These muscles, and the nerves supplying them, have been already considered (p. 138 *et seq.*, Vol. II.).

Course of a Ray of Light.—With the help of the diagram (Fig. 379) representing a vertical section of the eye from before backward, the mode in which, by means of the refracting media of the eye, an image of an object of sight is thrown on the retina, may be rendered intelligible. The rays of the cones of light emitted by the points A B, and every other point of an object placed before the eye, are first refracted, that is, are bent toward the axis of the cone, by the cornea C C, and the aqueous humor contained between it and the lens. The rays of each cone are again refracted and bent still more toward its central ray or axis by the anterior surface of the lens E E; and again as they pass out through its posterior surface into the less dense medium of the vitreous humor. For a lens has the power of refracting and causing the convergence of the rays of a cone of light, not only on their entrance from a rarer medium into its anterior convex surface, but also at their exit from its posterior convex surface into the rarer medium.

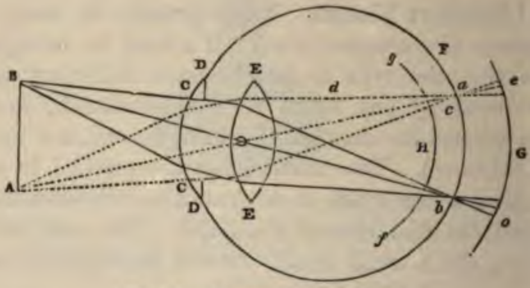


FIG. 379.—Course of a ray of light.

In this manner the rays of the cones of light issuing from the points A and B are again collected to points *a* and *b*; and, if the retina F be situated at *a* and *b*, perfect, though reversed, images of the points A and B will be formed upon it: but if the retina be not at *a* and *b*, but either before or behind that situation,—for instance, at H or G,—circular luminous spots *c* and *f*, or *e* and *o*, instead of points, will be seen; for at H the rays have not yet met, and at G they have already intersected each other, and are again diverging.

The retina must therefore be situated at the proper focal distance from the lens, otherwise a defined image will not be formed; or, in other words, the rays emitted by a given point of the object will not be collected into a corresponding point of focus upon the retina.

DEFECTS IN THE APPARATUS.

***A.* Defects in the Refracting Media.**—Under this head we may consider the defects known as (1) Myopia, (2) Hypermetropia, (3) Astigmatism, (4) Spherical Aberration, (5) Chromatic Aberration.

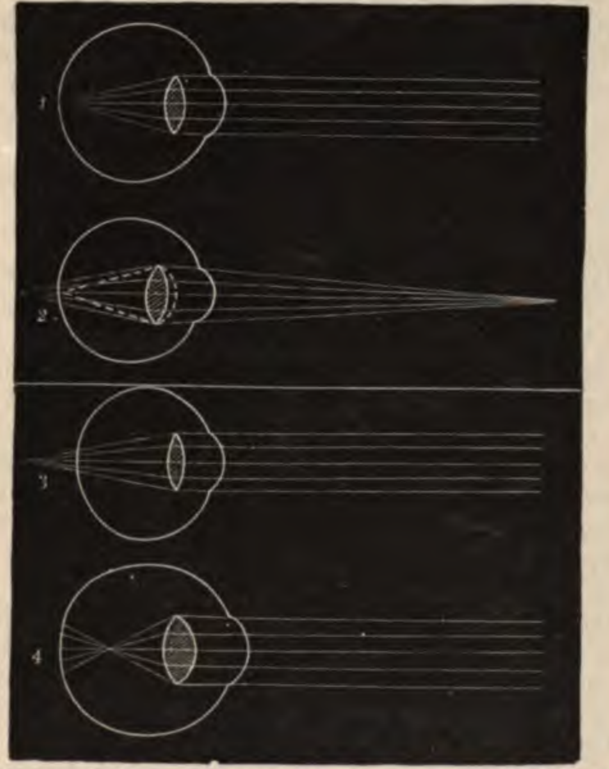


FIG. 380.—Diagrams showing—1, normal (emmetropic) eye bringing parallel rays exactly to a focus on the retina; 2, normal eye adapted to a near-point; without accommodation the rays would be focussed behind the retina, but by increasing the curvature of the anterior surface of the lens (shown by a dotted line) the rays are focussed on the retina (as indicated by the meeting of the two dotted lines); 3, *hypermetropic* eye; in this case the axis of the eye is shorter, and the lens flatter, than normal; parallel rays are focussed behind the retina; 4, *myopic* eye; in this case the axis of the eye is abnormally long, and the lens too convex; parallel rays are focussed in front of the retina.

The normal (emmetropic) eye is so adjusted that parallel rays are brought exactly to a focus on the retina without any effort of accommodation (1, Fig. 380). Hence all objects except near ones (practically all objects more than twenty feet off) are seen without any effort of accommodation: in other words, the far-point of the normal eye is at an infinite distance. In viewing near objects we are conscious of an effort (the contraction of the ciliary muscle) by which the anterior surface of the lens is rendered more convex, and rays which would otherwise be focussed *behind* the retina are converged upon the retina (see dotted lines, 2, Fig. 380).

1. **Myopia** (short-sight) (4, Fig. 380).—This defect is due to an abnormal elongation of the eyeball. The eye is usually larger than normal, and is always longer than normal; the lens is also probably too convex. The retina is too far from the lens, and consequently parallel rays are focussed in front of the retina, and, crossing, form little circles on the retina; thus the images of distant objects are blurred and indistinct. The eye is, as it were, permanently adjusted for a near-point. Rays from a point near the eye are exactly focussed in the retina. But those which issue from any object beyond a certain distance (*far-point*) cannot be distinctly focussed. This defect is corrected by *concave* glasses, which cause the rays entering the eye to diverge; hence they do not come to a focus so soon. Such glasses of course are only needed to give a clear vision of distant objects. For near objects, except in extreme cases, they are not required.

2. **Hypermetropia** (long-sight) (3, Fig. 380).—This is the reverse defect. The eye is too short and the lens too flat. Parallel rays are focussed *behind* the retina: an effort of accommodation is required to focus even parallel rays on the retina; and when they are divergent, as in viewing a near object, the accommodation is insufficient to focus them. Thus in well-marked cases distant objects require an effort of accommodation and near ones a very powerful effort. Thus the ciliary muscle is constantly acting. This defect is obviated by the use of *convex* glasses, which render the pencils of light more convergent. Such glasses are of course especially needed for near objects, as in reading, etc. They rest the eye by relieving the ciliary muscle from excessive work.

3. **Astigmatism.**—This defect, which was first discovered by Airy, is due to a greater curvature of the eye in one meridian than in others. The eye may be even myopic in one plane and hypermetropic in others. Thus vertical and horizontal lines crossing each other cannot both be focussed at once; one set stand out clearly and the others are blurred and indistinct. This defect, which is present in a slight degree in all eyes, is generally seated in the cornea, but occasionally in the lens as well; it may be corrected by the use of cylindrical glasses (*i.e.* curved only in one direction).

4. **Spherical Aberration.**—The rays of a cone of light from an object situated at the side of the field of vision do not meet all in the same point, owing to their unequal refraction; for the refraction of the rays which pass through the circumference of a lens is greater than that of

those traversing its central portion. This defect is known as *spherical aberration*, and in the camera, telescope, microscope, and other optical instruments, it is remedied by the interposition of a screen with a circular aperture in the path of the rays of light, cutting off all the marginal rays and only allowing the passage of those near the centre. Such correction is effected in the eye by the iris, which forms an annular diaphragm to cover the circumference of the lens, and to prevent the rays from passing through any part of the lens but its centre which corresponds to the pupil. The posterior surface of the iris is coated with pigment, to prevent the passage of rays of light through its substance. The image of an object will be most defined and distinct when the pupil is narrow, the object at the proper distance for vision,and the light abundant; so that, while a sufficient number of rays are admitted, the narrowness of the pupil may prevent the production of indistinctness of the image by *spherical aberration*. But even the image formed by the rays passing through the circumference of the lens, when the pupil is much dilated, as in the dark, or in a feeble light, may, under certain circumstances, be well defined.

Distinctness of vision is further secured by the outer surface of the retina as well as the posterior surface of the iris and the ciliary processes, being coated with black pigment, which absorbs any rays of light that may be reflected within the eye, and prevents their being thrown again upon the retina so as to interfere with the images there formed. The pigment of the retina is especially important in this respect; for with the exception of its outer layer the retina is very transparent, and if the surface behind it were not of a dark color, but capable of reflecting the light, the luminous rays which had already acted on the retina would be reflected again through it, and would fall upon other parts of the same membrane, producing both dazzling from excessive light, and indistinctness of the images.

5. **Chromatic Aberration.**—In the passage of light through an ordinary convex lens, decomposition of each ray into its elementary colored parts commonly ensues, and a colored margin appears around the image, owing to the unequal refraction which the elementary colors undergo. In optical instruments this, which is termed *chromatic aberration*, is corrected by the use of two or more lenses, differing in shape and density, the second of which continues or increases the refraction of the rays produced by the first, but by recombining the individual parts of each ray into its original white light, corrects any chromatic aberration which may have resulted from the first. It is probable that the unequal refractive power of the transparent media in front of the retina may be the means by which the eye is enabled to guard against the effect of chromatic aberration. The human eye is achromatic, however, only so long as the image is received at its focal distance upon the retina, or so long as the eye adapts itself to the different distances of sight. If either of these

conditions be interfered with, a more or less distinct appearance of colors is produced.

An ordinary ray of white light in passing through a prism, is refracted, *i.e.*, bent out of its course, but the different colored rays which go to make up white light are refracted in different degrees, and therefore appear as colored bands fading off into each other: thus a colored band known as the "spectrum" is produced, the colors of which are arranged as follows:—red, orange, yellow, green, blue, indigo, violet; of these the red ray is the least and the violet the most refracted. Hence, as Helmholtz has shown, a small white object cannot be accurately focussed on the retina, for if we focus for the red rays, the violet are out of focus, and *vice versâ:* such objects, if not exactly focussed, are often seen surrounded by a pale yellowish or bluish fringe.

For similar reasons a red surface looks nearer than a blue one at an equal distance, because, the red rays being less refrangible, a stronger effort of accommodation is necessary to focus them, and the eye is adjusted as if for a nearer object, and therefore the red surface appears nearer.

From the insufficient adjustment of the image of a small white object, it appears surrounded by a sort of halo or fringe. This phenomenon is termed *Irradiation.* It is from this reason that a white square on a black ground appears larger than a black square of the same size on white ground.

As an optical instrument, the *eye is superior to the camera* in the following, among many other particulars, which may be enumerated in detail. 1. The correctness of images even in a large field of view. 2. The simplicity and efficiency of the means by which chromatic aberration is avoided. 3. The perfect efficiency of its adaptation to different distances. In the photographic camera, it is well known that only a comparatively small object can be accurately focussed. In the photograph of a large object near at hand, the upper and lower limits are always more or less hazy, and vertical lines appear curved. This is due to the fact that the image produced by a convex lens is really slightly curved and can only be received without distortion on a slightly curved concave screen, hence the distortion on a *flat* surface of ground glass. It is different with the eye, since it possesses a concave background, upon which the field of vision is depicted, and with which the curved form of the image coincides exactly. Thus, the defect of the camera obscura is entirely avoided; for the eye is able to embrace a large field of vision, the margins of which are depicted distinctly and without distortion. If the retina had a plane surface like the ground glass plate in a camera, it must necessarily be much larger than is really the case if we were to see as much; moreover, the central portion of the field of vision alone would give a good clear picture. (Bernstein.)

B. **Defective Accommodation—Presbyopia.**—This condition is due to the gradual loss of the power of accommodation which is part of the general decay of old age. In consequence the patient would be obliged in reading to hold his book further and further away in order to focus the letters, till at last the letters are held too far for distinct vision. The defect is remedied by weak convex glasses, which are very commonly worn by old people. It is due chiefly to the gradual increase in density of the lens, which is unable to swell out and become convex when near objects are looked at, and also to a weakening of the ciliary muscle, and a general loss of elasticity in the parts concerned in the mechanism.

Visual Sensations.

Excitation of the Retina.—Light is the normal agent in the excitation of the retina, the only layer of which capable of reacting to the stimulus being the rods and cones. The proofs of this statement may be summed up thus:—

(1.) The point of entrance of the optic nerve into the retina, where the rods and cones are absent, is insensitive to light and is called the *blind spot*. The phenomenon itself is very readily demonstrated. If we direct one eye, the other being closed, upon a point at such a distance to the side of any object, that the image of the latter must fall upon the retina at the point of entrance of the optic nerve, this image is lost either instantaneously, or very soon. If, for example, we close the left eye, and direct the axis of the right eye steadily toward the circular spot here

● +

represented, while the page is held at a distance of about six inches from the eye, both dot and cross are visible. On gradually increasing the distance between the eye and the object, by removing the book farther and farther from the face, and still keeping the right eye steadily on the dot, it will be found that suddenly the cross disappears from view, while on removing the book still farther, it suddenly comes in sight again. The cause of this phenomenon is simply that the portion of retina which is occupied by the entrance of the optic nerve, is quite blind; and therefore that when it alone occupies the field of vision, objects cease to be visible. (2.) In the fovea centralis and macula lutea, which contain rods and cones but no optic nerve-fibres, light produces the greatest effect. In the latter, cones occur in larger numbers, and in the former cones without rods are found, whereas in the rest of the retina which is not so sensitive to light, there are fewer cones than rods. We may conclude, therefore, that cones are even more important to vision than rods. (3.) If a small lighted candle be moved to and fro at the side of and close to one eye in a dark room while the eyes look steadily forward into the darkness, a remarkable branching figure (*Purkinje's figures*) is seen floating before the eye, consisting of dark lines on a reddish ground. As the candle moves, the figure moves in the opposite direction, and from its whole appearance there can be no doubt that it is a reversed picture of the retinal vessels projected before the eye. The two large branching arteries passing up and down from the optic disc are clearly visible together with their minutest branches. A little to one side of the disc, in a part free from vessels, is seen the yellow spot in the form of a slight depression. This remarkable appearance is doubtless due to shadows of the retinal vessels cast by the candle. The branches of these vessels are chiefly distributed in the nerve-fibre and ganglionic layers; and since the light of the candle falls on the retinal vessels from in front, the shadow is cast behind them, and hence those elements of the retina which perceive the shadows must also lie behind the vessels. Here, then, we have a clear proof that the light-perceiving elements of the retina are not the fibres of the optic nerve forming the innermost layer of the retina, but the external layers of the retina, almost certainly the rods and cones, which indeed appear to be the special terminations of the optic nerve-fibres.

Duration of Visual Sensations.—The *duration* of the sensation produced by a luminous impression on the retina is always greater than that of the impression which produces it. However brief the luminous impression, the effect on the retina always lasts for about one-eighth of a second. Thus, supposing an object in motion, say a horse, to be revealed on a dark night by a flash of lightning. The object would be seen apparently for an eighth of a second, but it would not appear in motion; because, although the image remained on the retina for this time, it was really revealed for such an extremely short period (a flash of lightning being almost instantaneous) that no appreciable movement on the part of the object could have taken place in the period during which it was revealed to the retina of the observer. And the same fact is proved in a reverse way. The spokes of a rapidly revolving wheel are not seen as distinct objects, because at every point of the field of vision over which the revolving spokes pass, a given impression has not faded before another comes to replace it. Thus every part of the interior of the wheel appears occupied.

The duration of the *after-sensation*, produced by an object, is greater in a direct ratio with the duration of the impression which caused it. Hence the image of a bright object, as of the panes of a window through which the light is shining, may be perceived in the retina for a considerable period, if we have previously kept our eyes fixed for some time on it. But the image in this case is *negative*. If, however, after shutting the eyes for some time, we open them and look at an object for an instant, and again close them, the after-image is *positive*.

Intensity of Visual Sensations.—It is quite evident that the more luminous a body the more intense is the sensation it produces. But the intensity of the sensation is not *directly* proportional to the intensity of the luminosity of the object. It is necessary for light to have a certain intensity before it can excite the retina, but it is impossible to fix an arbitrary limit to the power of excitability. As in other sensations, so also in visual sensations, a stimulus may be too feeble to produce a sensation. If it be increased in amount sufficiently it begins to produce an effect which is increased on the increase of the stimulation; this increase in the effect is not *directly* proportional to the increase in the excitatión, but, according to *Fechner's law*, "as the logarithm of the stimulus," *i.e.*, in each sensation, there is a constant ratio between the increase in the stimulus and the increase in the sensation, this constant ratio for each sensation expresses the least perceptible increase in the sensation or minimal increment of excitation.

This law, which is true only within certain limits, may be best understood by an example. When the retina has been stimulated by the light of one candle, the light of two candles will produce a difference in sensation which can be distinctly felt. If, however, the first stimulus had been that of an electric light, the addition of the light of a candle would make no difference in the sensation. So, generally, for an additional stimulus to be felt, it may be proportionately small if the original stimulus have been small, and must be greater if the original stimulus have been great. The stimulus increases as the ordinary numbers, while the sensation increases as the logarithm.

The Ophthalmoscope.—Part of the light which enters the eye is absorbed, and produces some change in the retina, of which we shall treat further on; the rest is reflected.

Every one is perfectly familiar with the fact, that it is quite impossible to see the *fundus* or back of another person's eye by simply looking into it. The interior of the eye forms a perfectly black background to the pupil. The same remark applies to an ordinary photographic camera, and may be illustrated by the difficulty we experience in seeing into a room from the street through the window, unless the room be lighted within. In the case of the eye this fact is partly due to the feebleness of the light reflected from the retina, most of it being absorbed by the choroid, as mentioned above; but far more to the fact that every such ray is reflected straight back to the source of light (*e.g.*, candle), and cannot, therefore, be seen by the unaided eye without intercepting the incident light from the candle, as well as the reflected rays from the retina. This difficulty has been surmounted by the ingenious device of Helmholtz, now so extensively used, termed the *ophthalmoscope*. As at present used, it consists of a small slightly concave mirror, by which light is reflected from a candle into the eye. The observer looks through a hole in the mirror, and can thus explore the illuminated fundus; the entrance of the optic nerve and the retinal vessels being plainly visible.

Visual Purple.—The method by which a ray of light is able to stimulate the endings of the optic nerve in the retina in such a manner that a visual sensation is perceived by the cerebrum is not yet understood. It is supposed that the change effected by the agency of the light which falls upon the retina is in fact a chemical alteration in the protoplasm, and that this change stimulates the optic nerve-endings. The discovery of a certain temporary reddish-purple pigmentation of the outer limbs of the retinal rods in certain animals (*e.g.*, frogs) which have been killed in the dark, forming the so-called *visual purple*, appeared likely to offer some explanation of the matter, especially as it was also found that the pigmentation disappeared when the animal was exposed to light, and reappeared when the light was removed, and also that it underwent distinct changes of color when other than white light was used. The visual purple cannot however be absolutely essential to the due production of visual sensations, as it is absent from the retinal cones, and from the macula lutea and fovea centralis of the human retina, and does not appear to exist at all in the retinas of some animals, *e.g.*, bat, dove, and hen, which are, nevertheless, possessed of good vision.

If the operation be performed quickly enough, the image of an object may be fixed in the pigment on the retina by soaking the retina of an animal, which has been killed in the dark, in alum solution.

Electrical Currents.—According to the careful researches of Dewar and McKendrick, and of Holmgren, it appears that the stimulus of light is able to produce a variation of the natural electrical current of the retina. The current is at first increased and then diminished. McKendrick believes that this is the electrical expression of those chemical changes in the retina of which we have already spoken.

VISUAL PERCEPTIONS AND JUDGMENTS.

Reversion of the Image.—The direction given to the rays by their refraction is regulated by that of the central ray, or axis of the cone, toward which the rays are bent. The image of any point of an object is, therefore, as a rule (the exceptions to which need not here be stated), always formed in a line identical with the axis of the cone of light, as in the line of B *a*, or A *b* (Fig. 381), so that the spot where the image of any point will be formed upon the retina may be determined by prolonging the central ray of the cone of light, or that ray which traverses the centre of the pupil. Thus A *b* is the axis or central ray of the cone of light issuing from A; B *a* the central ray of the cone of light issuing from B; the image of A is formed at *b*, the image of B at *a*, in the inverted position; therefore what in the object was above is in the image below, and *vice versâ*,—the right hand part of the object is in the image to the left, the left-hand to the right. If an opening be made in an eye at its superior surface, so that the retina can be seen through the vitreous humor, this reversed image of any bright object, such as the windows of the room, may be perceived at the bottom of the eye. Or still better, if the eye of any albino animal, such as a white rabbit, in which the coats, from the absence of pigment, are transparent, is dissected clean, and held with the cornea toward the window, a very distinct image of the window completely inverted is seen depicted on the posterior translucent wall of the eye. Volkmann has also shown that a similar experiment may be successfully performed in a living person possessed of large prominent eyes, and an unusually transparent sclerotic.

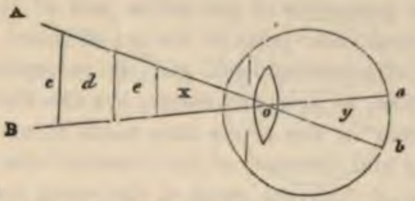


FIG. 381.—Diagram of the formation of the image on the retina.

An image formed at any point on the retina is referred to a point outside the eye, lying on a straight line drawn from the point on the retina outward through the centre of the pupil. Thus an image on the left side of the retina is referred by the mind to an object on the right side of the eye, and *vice versâ*. Thus all images on the retina are mentally, as it were, projected in front of the eye, and the objects are seen *erect* though the image on the retina is *reversed*. Much needless confusion and difficulty have been raised on this subject for want of remembering that when we are said to *see* an object, the mind is merely conscious of the picture on the retina, and when it refers it to the external object, or "projects" it outside the eye, it *necessarily* reverses it and sees the object as erect, though the retinal image is inverted. This is further corroborated by the sense of touch. Thus an object whose picture falls on the left half of the retina is reached by the right hand, and hence is said to lie to the *right*. Or, again, an object whose image is formed on the upper part of the retina is readily touched by the feet, and is therefore said to be in the *lower* part of the field, and so on.

Hence it is, also, that no discordance arises between the sensations of inverted vision and those of touch, which perceives everything in its erect position; for the images of all objects, even of our own limbs, in the retina, are equally inverted, and therefore maintain the same relative position.

Even the image of our hand, while used in touch, is seen inverted. The position in which we see objects, we call, therefore, the erect position. A mere lateral inversion of our body in a mirror, where the right hand occupies the left of the image, is indeed scarcely remarked: and there is but little discordance between the sensations acquired by touch in regulating our movements by the image in the mirror, and those of sight, as, for example, in tying a knot in the cravat. There is some want of harmony here, on account of the inversion being only lateral, and not complete in all directions.

The perception of the erect position of objects appears, therefore, to be the result of an act of the mind. And this leads us to a consideration of the several other properties of the retina, and of the co-operation of the mind in the several other parts of the act of vision. To these belong not merely the act of sensation itself and the perception of the changes produced in the retina, as light and colors, but also the conversion of the mere images depicted in the retina into ideas of an extended field of vision, of proximity and distance, of the form and size of objects, of the reciprocal influence of different parts of the retina upon each other, the simultaneous action of the two eyes, and some other phenomena.

Field of Vision.—The actual size of the field of vision depends on the extent of the retina, for only so many images can be seen at any one time as can occupy the retina at the same time; and thus considered, the retina, of which the affections are perceived by the mind, is itself the field of vision. But to the mind of the individual the size of the field of vision has no determinate limits; sometimes it appears very small, at another time very large; for the mind has the power of projecting images on the retina toward the exterior. Hence the mental field of vision is very small when the sphere of the action of the mind is limited to impediments near the eye: on the contrary, it is very extensive when the projection of the images on the retina toward the exterior, by the influence of the mind, is not impeded. It is very small when we look into a hollow body of small capacity held before the eyes; large when we look out upon the landscape through a small opening; more extensive when we look at the landscape through a window; and most so when our view is not confined by any near object. In all these cases the idea which we receive of the size of the field of vision is very different, although its absolute size is in all the same, being dependent on the extent of the retina. Hence it follows, that the mind is constantly co-operating in the acts of vision, so that at last it becomes difficult to say what belongs to mere sensation, and what to the influence of the mind. By a mental operation of this kind we obtain a correct idea of the size of individual objects, as well as of the extent of the field of vision. To illustrate this, it will be well to refer to Fig. 382.

The angle x, included between the decussating central rays of two cones of light issuing from different points of an object, is called the optical angle—*angulus opticus seu visorius*. This angle becomes larger, the greater the distance between the points A and B; and since the angles *x* and *y* are equal, the distance between the points *a* and *b* in the image on the retina increases as the angle becomes larger. Objects at different distances from the eye, but having the same optical angle *x*—for example, the objects *c*, *d*, and *e*,—must also throw images of equal size upon the retina; and, if they occupy the same angle of the field of vision, their image must occupy the same spot in the retina.

Nevertheless, these images appear to the mind to be of very unequal size when the ideas of distance and proximity come into play; for, from the image *a b*, the mind forms the conception of a visual space extending to *e*, *d*, or *c*, and of an object of the size which that represented by the image on the retina appears to have when viewed close to the eye, or under the most usual circumstances.

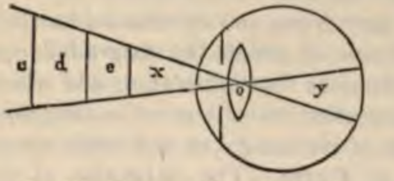


FIG. 382.—Diagram of the optical angle.

Estimation of Size.—Our estimate of the size of various objects is based partly on the visual angle under which they are seen, but much more on the estimate we form of their distance. Thus a lofty mountain many miles off may be seen under the same visual angle as a small hill near at hand, but we infer that the former is much the larger object because we know it is much further off than the hill. Our estimate of distance is often erroneous, and consequently the estimate of size also. Thus persons seen walking on the top of a small hill against a clear twilight sky appear unusually large, because we over-estimate their distance, and for similar reasons most objects in a fog appear immensely magnified. The same mental process gives rise to the idea of depth in the field of vision; this idea being fixed in our mind principally by the circumstance that, as we ourselves move forward, different images in succession become depicted on our retina, so that we seem to pass between these images, which to the mind is the same thing as passing between the objects themselves.

The action of the sense of vision in relation to external objects is, therefore, quite different from that of the sense of touch. The objects of the latter sense are immediately present to it; and our own body, with which they come into contact, is the measure of their size. The part of a table touched by the hand appears as large as the part of the hand receiving an impression from it, for a part of our body in which a sensation is excited, is here the measure by which we judge of the magnitude of the object. In the sense of vision, on the contrary, the images of objects are mere fractions of the objects themselves realized upon the retina, the extent of which remains constantly the same. But the imagination, which analyzes the sensations of vision, invests the images of objects, together with the whole field of vision in the retina, with very varying dimensions; the relative size of the image in proportion to the whole field of vision, or of the affected parts of the retina to the whole retina, alone remaining unaltered.

Estimation of Direction.—The direction in which an object is seen, depends on the part of the retina which receives the image, and on the distance of this part from, and its relation to, the central point of the retina. Thus, objects of which the images fall upon the same parts of the retina lie in the same visual direction; and when, by the action of the mind, the images or affections of the retina are projected into the exterior world, the relation of the images to each other remains the same.

Estimation of Form.—The estimation of the *form of bodies* by sight is the result partly of the mere sensation, and partly of the association of ideas. Since the form of the images perceived by the retina depends wholly on the outline of the part of the retina affected, the sensation alone is adequate to the distinction of only superficial forms of each other, as of a square from a circle. But the idea of a solid body as a sphere, or a body of three or more dimensions, *e.g.*, a cube, can only be attained by the action of the mind constructing it from the different superficial images seen in different positions of the eye with regard to the object, and, as shown by Wheatstone and illustrated in the *stereoscope*, from two different perspective projections of the body being presented simultaneously to the mind by the two eyes. Hence, when, in adult age, sight is suddenly restored to persons blind from infancy, all objects in the field of vision appear at first as if painted flat on one surface; and no idea of solidity is formed until after long exercise of the sense of vision combined with that of touch.

The *clearness* with which an object is perceived irrespective of accommodation, would appear to depend largely on the number of rods and cones which its retinal image covers. Hence the nearer an object is to the eye (within moderate limits) the more clearly are all its details seen. Moreover, if we want carefully to examine any object, we always direct the eyes straight to it, so that its image shall fall on the yellow spot where an image of a given area will cover a larger unmber of cones than anywhere else in the retina. It has been found that the images of two points must be at least $\frac{1}{12000}$ in. apart on the yellow spot in order to be distinguished separately; if the images are nearer together, the points appear as one. The diameter of each one in this part of the retina is about $\frac{1}{12000}$ in.

Estimation of Movement.—We judge of the *motion* of an object, partly from the motion of its image over the surface of the retina, and partly from the motion of our eyes following it. If the image upon the retina moves while our eyes and our body are at rest, we conclude that the object is changing its relative position with regard to ourselves. In such a case the movement of the object may be apparent only, as when we are standing upon a body which is in motion, such as a ship. If, on the other hand, the image does not move with regard to the retina, but remains fixed upon the same spot of that membrane, while our eyes follow the moving body, we judge of the motion of the object by the sensation of the muscles in action to move the eye. If the image moves over the surface of the retina while the muscles of the eye are acting at the same time in a manner corresponding to this motion, as in reading, we infer that the object is stationary, and we know that we are merely altering the relations of our eyes to the object. Sometimes the object appears to move when both object and eye are fixed, as in vertigo.

The mind can, by the faculty of *attention*, concentrate its activity more or less exclusively upon the sense of sight, hearing, and touch alternately. When exclusively occupied with the action of one sense, it is scarcely conscious of the sensations of the others. The mind, when deeply immersed in contemplations of another nature, is indifferent to the actions of the sense of sight, as of every other sense. We often, when deep in thought, have our eyes open and fixed, but see nothing, because of the stimulus of ordinary light being unable to excite the brain to perception, when otherwise engaged. The attention which is thus necessary for vision, is necessary also to analyze what the field of vision presents. The mind does not perceive all the objects presented by the field of vision at the same time with equal acuteness, but directs itself first to one and then to another. The sensation becomes more intense, according as the particular object is at the time the principal object of mental contemplation. Any compound mathematical figure produces a different impression according as the attention is directed exclusively to one or the other part of it. Thus in Fig. 383, we may in succession have a vivid perception of the whole, or of distinct parts only; of the six triangles near the outer circle, of the hexagon in the middle, or of the three large triangles. The more numerous and varied the parts of which a figure is composed, the more scope does it afford for the play of the attention. Hence it is that architectural ornaments have an enlivening effect on the sense of vision, since they afford constantly fresh subject for the action of the mind.

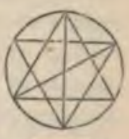


FIG. 383.

Color Sensations.—If a ray of sunlight be allowed to pass through a prism, it is decomposed by its passage into rays of different colors, which are called the colors of the spectrum; they are red, orange, yellow, green, blue, indigo, and violet. The red rays are the least turned out of their course by the prism, and the violet the most, whilst the other colors occupy in order places between these two extremes. The differences in the color of the rays, depend upon the number of vibrations producing each, the red rays being the least rapid and the violet the most. In addition to the colored rays of the spectrum, there are others which are invisible, but which have definite properties, those to the left of the red, and less refrangible, being the calorific rays which act upon the thermometer, and those to the right of the violet which are called the actinic or chemical rays, which have a powerful chemical action. The rays which can be perceived by the brain as visual rays, *i.e.*, the colored rays, must stimulate the retina in some special manner in order that colored vision may result, and two chief explanations of the method of stimulation have been suggested. The one, originated by Young and elaborated by Helmholtz, holds that there are three primary colors, viz., red, green, and violet, and that in the retina are contained rods or cones which answer to each of these primary colors, whereas the innumerable intermediate shades of color are produced by stimulation of the three primary color terminals in different degrees; the sensation of white being produced when the three elements are equally excited. Thus if the retina be stimulated by rays of certain wave length, at the red end of the spectrum, the terminals of the other colors, green and violet, are hardly stimulated at all, but the red terminals being strongly stimulated, the resulting sensation is red. The orange rays excite the red terminals considerably, the green rather more, and the violet slightly, the resulting sensation being that of orange, and so on.

The second theory of color (Hering's) supposes that there are six primary color sensations, of three pair of antagonistic or complemental colors, black and white, red and green, and yellow and blue, and that these are produced by the changes either of disintegration or of assimilation taking place in certain substances, somewhat it may be supposed of the nature of the visual purple, which (the theory supposes to) exist in the retina. Each of the substances corresponding to a pair of colors, being capable of undergoing two changes, one of construction and the other of disintegration, with the result of producing one or other color. For instance, in the white-black substance, when disintegration is in excess of construction or assimilation, the sensation is white, and when assimilation is in excess of disintegration the reverse is the case; and similarly with the red-green substance, and with the yellow-blue substance. When the repair and disintegration are equal with the first substance, the visual sensation is grey; but in the other pairs when this is the case, no sensation occurs. The rays of the spectrum to the left produce changes in the red-green substance only, with a resulting sensation of red, whilst the (orange) rays further to the right affect both the red-green and the yellow-blue substances; blue rays cause constructive changes in the yellow-blue substance, but none in the red-green, and so on. These changes produced in the visual substances in the retina are perceived by the brain as sensations of color.

The spectra left by the images of white or luminous objects, are ordinarily white or luminous; those left by dark objects are dark. Sometimes, however, the relation of the light and dark parts in the image may, under certain circumstances, be reversed in the spectrum; what was bright may be dark, and what was dark may appear light. This occurs whenever the eye, which is the seat of the spectrum of a luminous object, is not closed, but fixed upon another bright or white surface, as a white wall, or a sheet of white paper. Hence the spectrum of the sun, which, while light is excluded from the eye, is luminous, appears black or grey when the eye is directed upon a white surface. The explanation of this is, that the part of the retina which has received the luminous image remains for a certain period afterward in an exhausted or less sensitive state, while that which has received a dark image is in an unexhausted, and therefore much more excitable condition.

The ocular spectra which remain after the impression of colored objects upon the retina are always colored; and their color is not that of the object, or of the image produced directly by the object, but the opposite, or *complemental* color. The spectrum of a red object is, therefore, green; that of a green object, red; that of violet, yellow; that of yellow, violet, and so on. The reason of this is obvious. The part of the retina which receives, say, a red image, is wearied by that particular color, but remains sensitive to the other rays which with red make up white light; and, therefore, these by themselves reflected from a white object produce a green hue. If, on the other hand, the first object looked at be green, the retina being tired of green rays, receives a red image when the eye is

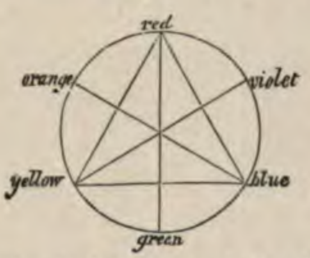


FIG. 384.—Diagram of the various simple and compound colors of light, and those which are complemental of each other, *i.e.*, which, when mixed, produce a neutral grey tint. The three simple colors, red, yellow, and blue, are placed at the angles of an equilateral triangle, which are connected together by means of a circle; the mixed colors, green, orange, and violet, are placed intermediate between the corresponding simple or homogeneous colors, and the complemental colors, of which the pigments, when mixed, would constitute a grey, and of which the prismatic spectra would together produce a white light, will be found to be placed in each case opposite to each other, but connected by a line passing through the centre of the circle. The figure is also useful in showing the further shades of color which are complementary of each other. If the circle be supposed to contain every transition of color between the six marked down, those which, when united, yield a white or grey color, will always be found directly opposite to each other; thus, for example, the intermediate tint between orange and red is complemental of the middle tint between green and blue.

turned to a white object. And so with the other colors; the retina while fatigued by yellow rays will suppose an object to be violet, and *vice versâ;* the size and shape of the spectrum corresponding with the size and shape of the original object looked at. The colors which thus reciprocally excite each other in the retina are those placed at opposite points of the circle in Fig. 384. The peripheral parts of the retina have no perception of *red.* The area of the retina which is capable of receiving impressions of color is slightly different for each color.

Color Blindness or Daltonism.—*Daltonism* or color-blindness is a by no means uncommon visual defect. One of the commonest forms is the inability to distinguish between red and green. The simplest explanation of such a condition is, that the elements of the retina which receive the impression of red, etc., are absent, or very imperfectly developed, or, according to the other theory, that the red-green substance is absent from the retina. Other varieties of color blindness in which the other color-perceiving elements are absent have been shown to exist occasionally.

OF THE RECIPROCAL ACTION OF DIFFERENT PARTS OF THE RETINA ON EACH OTHER.

Although each elementary part of the retina represents a distinct portion of the field of vision, yet the different elementary parts, or sensitive points of that membrane, have a certain influence on each other; the particular condition of one influencing that of another, so that the image perceived by one part is modified by the image depicted in the other. The phenomena which result from this relation between the different parts of the retina, may be arranged in two classes; the one including those where the condition existing in the greater extent of the retina is imparted to the remainder of that membrane; the other, consisting of those in which the condition of the larger portion of the retina excites, in the less extensive portion, the opposite condition.

1. When two opposite impressions occur in contiguous parts of an image on the retina, the one impression is, under certain circumstances, modified by the other. If the impressions occupy each one-half of the image, this does not take place; for in that case their actions are equally balanced. But if one of the impressions occupies only a small part of the retina, and the other the greater part of its surface, the latter may, if long continued, extend its influence over the whole retina, so that the opposite less extensive impression is no longer perceived, and its place becomes occupied by the same sensation as the rest of the field of vision. Thus, if we fix the eye for some time upon a strip of colored paper lying upon a white surface, the image of the colored object, especially when it

falls on the lateral parts of the retina, will gradually disappear, and the white surface be seen in its place.

2. In the second class of phenomena, the affection of one part of the retina influences that of another part, not in such a manner as to obliterate it, but so as to cause it to become the contrast or opposite of itself. Thus a grey spot upon a white ground appears darker than the same tint of grey would do if it alone occupied the whole field of vision, and a shadow is always rendered deeper when the light which gives rise to it becomes more intense, owing to the greater contrast.

The former phenomena ensue gradually, and only after the images have been long fixed on the retina; the latter are instantaneous in their production, and are permanent.

In the same way, also, colors may be produced by contrast. Thus, a very small dull grey strip of paper, lying upon an extensive surface of any bright color, does not appear grey, but has a faint tint of the color which is the complement of that of the surrounding surface. A strip of grey paper upon a green field, for example, often appears to have a tint of red, and when lying upon a red surface, a greenish tint; it has an orange-colored tint upon a bright blue surface, and a bluish tint upon an orange-colored surface; a yellowish color upon a bright violet, and a violet tint upon a bright yellow surface. The color excited thus, as a contrast to the exciting color, being wholly independent of any rays of the corresponding color acting from without upon the retina, must arise as an opposite or

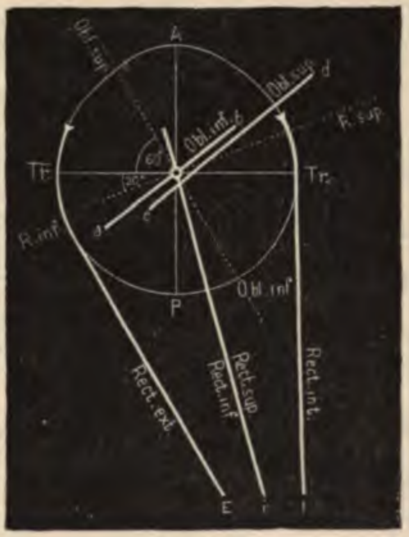


FIG. 385.—Diagram of the axes of rotation to the eye. The thin lines indicate axes of rotation, the thick the position of muscular attachment. (Modified from Fick.)

antagonistic condition of that membrane; and the opposite conditions of which the retina thus becomes the subject would seem to balance each other by their reciprocal reaction. A necessary condition for the production of the contrasted colors is, that the part of the retina in which the new color is to be excited, shall be in a state of comparative repose; hence the small object itself must be grey. A second condition is, that the color of the surrounding surface shall be very bright, that is, it shall contain much white light.

Movements of the Eye.—The eyeball possesses movement around three axes indicated in Fig. 385, viz., an antero-posterior, a vertical, and a transverse, passing through a centre of rotation a little behind the centre of the optic axis. The movements are accomplished by pairs of muscles.

Movements.	*By what muscles accomplished.*
Inward	Internal rectus.
Outward	External rectus.
Upward	Superior rectus. Inferior oblique.
Downward	Inferior rectus. Superior oblique.
Inward and upward . . .	Internal and superior rectus. Inferior oblique.
Inward and downward . . .	Internal and inferior rectus. Superior oblique.
Outward and upward . . .	External and superior rectus. Inferior oblique.
Outward and downward . .	External and inferior rectus. Superior oblique.

Of the Simultaneous Action of the Two Eyes.

Although the sense of sight is exercised by two organs, yet the impression of an object conveyed to the mind is single. Various theories have been advanced to account for this phenomenon. By Gall it was supposed that we do not really employ both eyes simultaneously in vision, but always see with only one at a time. This especial employment of one eye in vision certainly occurs in persons whose eyes are of very unequal focal distance, but in the majority of individuals both eyes are simultaneously in action, in the perception of the same object; this is shown by the double images seen under certain conditions. If two fingers be held up before the eyes, one in front of the other, and vision be directed to the more distant, so that it is seen singly, the nearer will appear double; while, if the nearer one be regarded, the most distant will be seen double; and one of the double images in each case will be found to belong to one eye, the other to the other eye.

Diplopia.—Single vision results only when certain parts of the two retinæ are affected simultaneously; if different parts of the retinæ receive the image of the object, it is seen double. This may be readily illustrated as follows:—The eyes are fixed upon some near object, and one of them is pressed by the thumb so as to be turned slightly in or out; two images of the object (*Diplopia* or Double Vision) are at once perceived, just as is frequently the case in persons who squint. This diplopia is due to the fact that the images of the object do not fall on corresponding points in the two retinæ.

The parts of the retinæ in the two eyes which thus correspond to each other in the property of referring the images which affect them simultaneously to the same spot in the field of vision, are, in man, just those parts which would correspond to each other, if one retina were placed exactly in front of, and over the other (as in Fig. 386, c). Thus the outer lateral portion of one eye corresponds to, or, to use a better term, is identical with, the inner portion of the other eye; or *a* of the eye A (Fig. 386), with *a′* of the eye B. The upper part of one retina is also identical with the upper part of the other; and the lower parts of the two eyes are identical with each other.

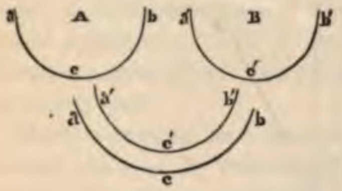


Fig. 386.

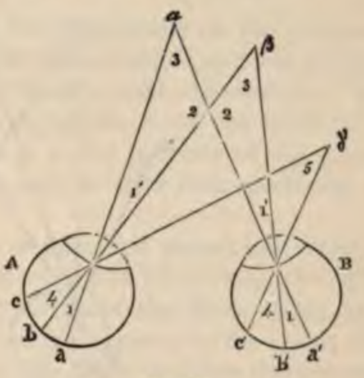


Fig. 387.

This is proved by a simple experiment. Pressure upon any part of the ball of the eye, so as to affect the retina, produces a luminous circle, seen at the opposite side of the field of vision to that on which the pressure is made. If, now, in a dark room, we press with the finger at the upper part of one eye, and at the lower part of the other, two luminous circles are seen, one above the other: so, also, two figures are seen when pressure is made simultaneously on the two outer or the two inner sides of both eyes. It is certain, therefore, that neither the upper part of one retina and the lower part of the other are identical, nor the outer lateral parts of the two retinæ, nor their inner lateral portions. But if pressure be made with the fingers upon both eyes simultaneously at their lower part, one luminous ring is seen at the middle of the upper part of the field of vision; if the pressure be applied to the upper part of both eyes a single luminous circle is seen in the middle of the field of vision below. So, also, if we press upon the outer side *a* of the eye A, and upon the inner side *a'* of the eye B, a single spectrum is produced, and is apparent at the extreme right of the field of vision; if upon the point *b* of one eye, and the point *b'* of the other, a single spectrum is seen to the extreme left.

The spheres of the two retinæ may, therefore, be regarded as lying one over the other, as in C, Fig. 386; so that the left portion of one eye lies over the identical left portion of the other eye, the right portion of one eye over the identical right portion of the other eye; and with the upper and lower portions of the two eyes, *a* lies over *a'*, *b* over *b'*, and *c* over *c'*. The points of the one retina intermediate between *a* and *c* are again identical with the corresponding points of the other retina between *a'* and *c'*; those between *b* and *c* of the one retina, with those between *b'* and *c'* of the other. If the axes of the eyes, A and B (Fig. 388), be so directed that they meet at *α*, an object at *α* will be seen singly, for the point *a* of the one retina, and *a'* of the other, are identical. So, also, if the object *β* be so situated that its image falls in both eyes at the same distance from the central point of the retina,—namely, at *b* in the one eye, and at *b'* in the other,—*β* will be seen single, for it affects identical parts of the two retinæ. The same will apply to the object *γ*.

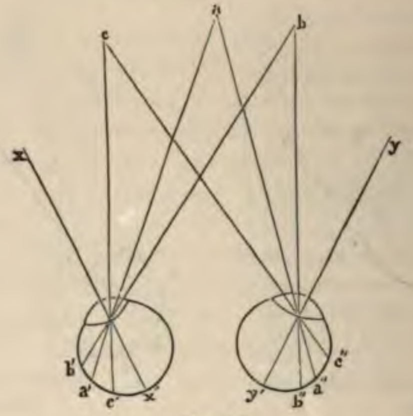


FIG. 388.

In quadrupeds, the relation between the identical and non-identical parts of the retina cannot be the same as in man; for the axes of their eyes generally diverge, and can never be made to meet in one point of an object. When an animal regards an object situated directly in front of it, the image of the object must fall, in both eyes, on the outer portion of the retinæ. Thus, the image of the object a (Fig. 389) will fall at a' in one, and at a'' in the other: and these points a' and a'' must be identical. So, also, for distinct and single vision of objects, b or c, the points $b'$and b'' or c' c'', in the two retinæ, on which the images of these objects fall, must be identical. All points of the retina in each eye which receive rays of light from lateral objects only, can have no corresponding identical points in the retina of the other eye; for otherwise two objects, one situated to the right and the other to the left, would appear to lie in the same spot of the field of vision. It is probable, therefore, that there are in the eyes of animals, parts of the retinæ which are identical, and parts which are not identical, *i.e.*, parts in one which have no corresponding parts in the other eye. And the relation of the two retinæ to each other in the field of vision may be represented as in Fig. 389.

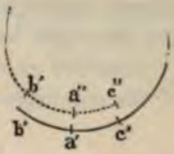


Fig. 389.

Binocular Vision.—The cause of the impressions on the identical points of the two retinæ giving rise to but one sensation, and the perception of a single image, must either lie in the structural organization of the deeper or cerebral portion of the visual apparatus, or be the result of a mental operation; for in no other case is it the property of the corresponding nerves of the two sides of the body to refer their sensations as one to one spot.

Many attempts have been made to explain this remarkable relation between the eyes, by referring it to anatomical relation between the optic nerves. The circumstance of the inner portion of the fibres of the two optic nerves decussating at the commissure and passing to the eye of the opposite side, while the outer portion of the fibres continue their course to the eye of the same side, so that the left side of both retinæ is formed from one root of the nerves, and the right side of both retinæ from the outer root, naturally led to an attempt to explain the phenomenon by this distribution of the fibres of the nerves. And this explanation is favored by cases in which the entire of one side of the retina, as far as the central point in both eyes, sometimes becomes insensible. But Müller shows the inadequateness of this theory to explain the phenomenon, unless it be supposed that each fibre in each cerebral portion of the optic nerves divides in the optic commissure into two branches for the identical points of the two retinæ, as is shown in A, Fig. 390. But there is no foundation for such supposition.

By another theory it is assumed that each optic nerve contains exactly the same number of fibres as the other, and that the corresponding fibres of the two nerves are united in the Sensorium (as in Fig. 390, B). But in this theory no account is taken of the partial decussation of the fibres of the nerves in the optic commissure.

According to a third theory, the fibres a and a', Fig. 390, C, coming from identical points of the two retinæ, are in the optic commissure brought into one optic nerve, and in the brain either are united by a loop or spring from the same point. The same disposition prevails in the case of the identical fibres *b* and *b′*. According to this theory the left half of each retina would be represented in the left hemisphere of the brain, and the right half of each retina in the right hemisphere.

Another explanation is founded on the fact, that at the anterior part of the commissure of the optic nerve, certain fibres pass across from the distal portion of one nerve to the corresponding portion of the other nerves, as if they were commissural fibres forming a connection between the retinæ of the two eyes. It is supposed, indeed, that these fibres may connect the corresponding parts of the two retinæ, and may thus explain their unity of action; in the same way that corresponding parts of the cerebral hemispheres are believed to be connected together by the commissural fibres of the corpus callosum, and so enabled to exercise unity of function.

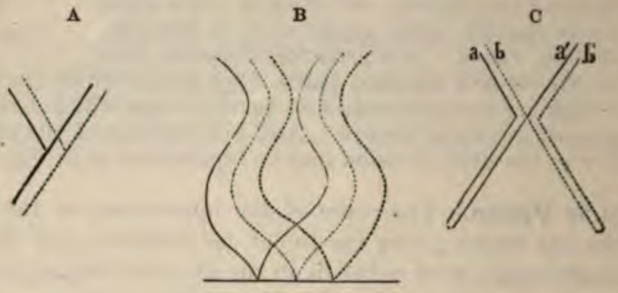


FIG. 390.

Judgment of Solidity.—On the whole, it is probable, that the power of forming a single idea of an object from a double impression conveyed by it to the eyes is the result of a mental act. This view is supported by the same facts as those employed by Wheatstone to show that this power is subservient to the purpose of obtaining a right perception of bodies raised in relief. When an object is placed so near the eyes that to view it the optic axes must converge, a different perspective projection of it is seen by each eye, these perspectives being more dissimilar as the convergence of the optic axes becomes greater. Thus, if any figure of three dimensions, an outline cube, for example, be held at a moderate distance before the eyes, and viewed with each eye successively while the head is kept perfectly steady, A (Fig. 391) will be the picture presented to the right eye, and B that seen by the left eye. Wheatstone has shown that on this circumstance depends in a great measure our conviction of the solidity of an object, or of its projection in relief. If different perspective drawings of a solid body, one representing the image seen by the right eye, the other that seen by the left (for example, the drawing of a cube, A, B, Fig. 391), be presented to corresponding parts of the two retinæ, as may be readily done by means of the stereoscope, the mind will perceive not merely a single representation of the object, but a body projecting in relief, the exact counterpart of that from which the drawings were made.

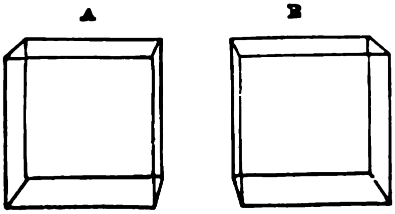


FIG. 391.

By transposing two stereoscopic pictures a reverse effect is produced: the elevated parts appear to be depressed, and *vice versâ*. An instrument contrived with this purpose is termed a *pseudoscope*. Viewed with this instrument a bust appears as a hollow mask, and as may readily be imagined the effect is most bewildering.

CHAPTER XX.

GENERATION AND DEVELOPMENT.

THE several organs and functions of the human body which have been considered in the previous chapters, have relation to the individual being. We have now to consider those organs and functions which are destined for the propagation of the species. These comprise the several provisions made for the formation, impregnation, and development of the ovum, from which the embryo or fœtus is produced and gradually perfected into a fully-formed human being.

The organs in the two sexes concerned in effecting these objects are named the Generative organs, or Sexual apparatus.

GENERATIVE ORGANS OF THE FEMALE.

The female organs of generation (Fig. 392) consist of two *Ovaries*, whose function is the formation of ova; of a *Fallopian tube*, or oviduct, connected with each ovary, for the purpose of conducting the ovum from the ovary to the *Uterus*, or cavity in which, if impregnated, it is retained until the embryo is fully developed, and fitted to maintain its existence in-

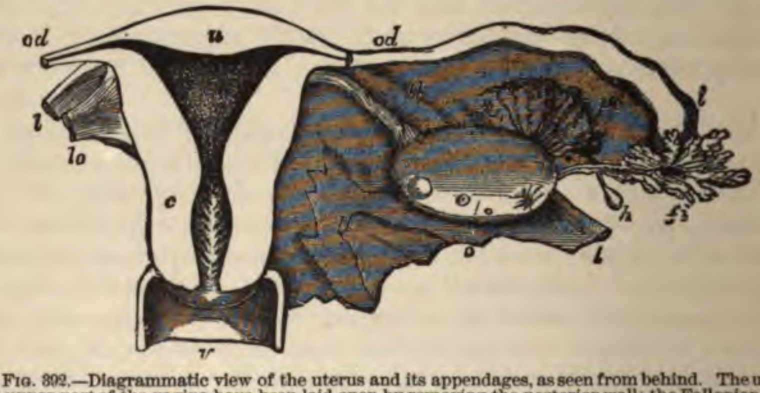


FIG. 392.—Diagrammatic view of the uterus and its appendages, as seen from behind. The uterus and upper part of the vagina have been laid open by removing the posterior wall; the Fallopian tube, round ligament, and ovarian ligament have been cut short, and the broad ligament removed on the left side; *u*, the upper part of the uterus; *c*, the cervix opposite the os internum; the triangular shape of the uterine cavity is shown, and the dilatation of the cervical cavity with the rugæ termed arbor vitæ; *v*, upper part of the vagina; *od*, Fallopian tube or oviduct; the narrow communication of its cavity with that of the cornu of the uterus on each side is seen; *l*, round ligament; *lo*, ligament of the ovary; *o*, ovary; *i*, wide outer part of the right Fallopian tube; *fi*, its fimbriated extremity; *po*, parovarium; *h*, one of the hydatids frequently found connected with the broad ligament. ½ (Allen Thomson.)

dependently of internal connection with the parent; and, lastly, of a canal, or *Vagina*, with its appendages, for the reception of the male generative organs in the act of copulation, and for the subsequent discharge of the fœtus.

Ovaries.—The *ovaries* are two oval compressed bodies, situated in the cavity of the pelvis, one on each side, enclosed in the folds of the broad ligament. Each ovary measures about an inch and a half in length, three-quarters of an inch in width, and nearly half an inch in thickness, and is attached to the uterus by a narrow fibrous cord (the ligament of the ovary), and, more slightly, to the Fallopian tubes by one of the fimbriæ into which the walls of the extremity of the tube expand.

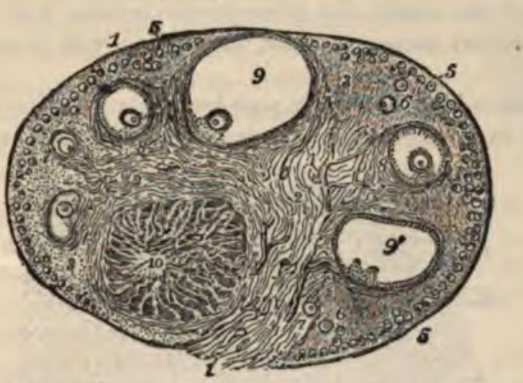


FIG. 393.—View of a section of the prepared ovary of the cat. 1, outer covering and free border of the ovary; 1′, attached border; 2. the ovarian stroma, presenting a fibrous and vascular structure; 3, granular substance lying external to the fibrous stroma; 4, blood-vessels; 5, ovigerms in their earliest stages occupying a part of the granular layer near the surface; 6, ovigerms which have begun to enlarge and to pass more deeply into the ovary; 7, ovigerms round which the Graafian follicle and tunica granulosa are now formed, and which have passed somewhat deeper into the ovary and are surrounded by the fibrous stroma; 8, more advanced Graafian follicle with the ovum imbedded in the layer of cells constituting the proligerous disc; 9, the most advanced follicle containing the ovum, etc.; 9′, a follicle from which the ovum has accidentally escaped; 10, corpus luteum. 6-1. (Schrön.)

Structure.—The ovary is developed by a *capsule* of dense fibro-cellular tissue, covered on the outside by epithelium (germ-epithelium), the cells of which, although continuous with, and originally derived from, the squamous epithelium of the peritoneum, are short columnar.

The term *germ-epithelium* is used on account of the relation which it bears in early life to the development of the ova; the ova being formed by certain of these epithelial cells, which, becoming modified in structure, are gradually enclosed in the ovarian stroma. (Waldeyer.) (See Fig. 394.)

The internal structure of the organ consists of a peculiar soft fibrous tissue, or *stroma*, abundantly supplied with blood-vessels, and having embedded in it, in various stages of development, numerous minute follicles or vesicles, the *Graafian vesicles*, or sacculi, containing the ova (Fig. 394).

Graafian Vesicles.—If the human ovary be examined at any period between early infancy and advanced age, but especially during that period of life in which the power of conception exists, it will be found to contain a number of small vesicles or membranous sacs of various sizes; these have been already alluded to as the *follicles* or *vesicles* of *De Graaf*, the anatomist who first accurately described them; they are sometimes called *ovisacs*.

At their first formation, the Graafian vesicles are near the surface of the stroma of the ovary, but subsequently become more deeply placed; and, again, as they increase in size, make their way toward the surface (Fig. 394).

When mature, they form little prominences on the exterior of the ovary, covered only by a thin layer of condensed fibrous tissue and epithelium. Each follicle has an external membranous envelope, comprised of fine fibrous tissue, and connected with the surrounding stroma of the ovary by networks of blood-vessels. This envelope or tunic is lined with a layer of nucleated cells, forming a kind of epithelium or internal tunic, and named *membrana granulosa*. The cavity of the follicle is filled with an albuminous fluid in which microscopic granules float; and it contains also the *ovum*.

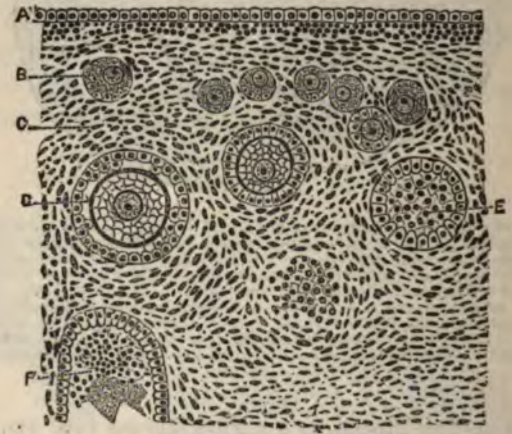


FIG. 394.—Section of the ovary of a cat. A, germinal epithelium; B, immature Graafian follicle; C, stroma of ovary; D, vitelline membrane containing the ovum; E, Graafian follicle showing lining cells; F, follicle from which the ovum has fallen out. (V. D. Harris.)

Ovum.—The ovum is a minute spherical body situated, in immature follicles, near the centre; but in those nearer maturity, in contact with the membrana granulosa at that part of the follicle which forms a prominence on the surface of the ovary. The cells of the membrana-granuloso are at that point more numerous than elsewhere, and are heaped around the ovum, forming a kind of granular zone, the *discus proligerus* (Fig. 395).

In order to examine an ovum, one of the Graafian vesicles, it matters not whether it be of small size or arrived at maturity, should be pricked, and the contained fluid received upon a slide. The ovum then, being found in the midst of the fluid by means of a simple lens, may be further examined with higher microscopic powers. Owing to its globular form, however, its structure cannot be seen until it is subjected to gentle pressure.

The human ovum measures about $\frac{1}{120}$ of an inch. Its external investment is a transparent membrane, about $\frac{1}{2500}$ of an inch in thickness, which under the microscope appears as a bright ring (4, Fig. 395), bounded externally and internally by a dark outline; it is called the *zona pellucida*, or *vitelline membrane*. It adheres externally to the heap of cells constituting the *discus proligerus*. Within this transparent investment or zona pellucida, and usually in close contact with it, lies the yolk or vitellus which is composed of granules and globules of various sizes, imbedded in a more or less fluid substance. The smaller granules, which are the more numerous, resemble in their appearance, as well as their constant motion, pigment-granules. The larger granules or globules, which have the aspect of fat-globules, are in greatest number at the periphery of the yolk. The number of the granules is, according to Bischoff, greatest in the ova of carnivorous animals. In the human ovum their quantity is comparatively small.

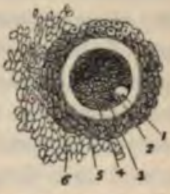


FIG. 395.—Ovum of the sow. 1, germinal spot; 2, germinal vesicle; 3, yolk; 4, zona pellucida; 5, discus proligerus; 6, adherent granules or cells. (Barry.)

In the substance of the yolk is imbedded the *germinal vesicle*, or vesicula germinativa (2, Fig. 395). This vesicle is of greatest relative size in the smallest ova, and is in them surrounded closely by the yolk, nearly in the centre of which it lies. During the development of the ovum, the germinal vesicle increases in size much less rapidly than the yolk, and comes to be placed near to its surface. It is about $\frac{1}{720}$ of an inch in diameter. It consists of a fine, transparent, structureless membrane, containing a clear, watery fluid, in which are sometimes a few granules; and at that part of the periphery of the germinal vesicle which is nearest to the periphery of the yolk is situated the *germinal spot* (*macula germinativa*), a finely granulated substance, of a yellowish color, strongly refracting the rays of light, and measuring about $\frac{1}{3000}$ of an inch in diameter.

Such are the parts of which the Graafian follicle and its contents, including the ovum, are composed. With regard to the mode and order of development of these parts there is considerable uncertainty; but it seems most likely that the ovum is formed before the Graafian vesicle or ovisac.

With regard to the parts of the *ovum* first formed, it appears certain that the formation of the germinal vesicle precedes that of the yolk and zona pellucida, or vitelline membrane. Whether the germinal spot is formed first, and the germinal vesicle afterward developed around it, cannot be decided in the case of vertebrate animals; but the observations of Kölliker and Bagge on the development of the ova of intestinal worms show that in these animals, the first step in the process is the production of round bodies resembling the germinal spots of ova, the germinal vesicles being subsequently developed around these in the form of transparent membranous cells.

From the earliest infancy, and through the whole fruitful period of life, there appears to be a constant formation, development, and maturation of Graafian vesicles, with their contained ova. Until the period of puberty, however, the process is comparatively inactive; for, previous to this period, the ovaries are small and pale, the Graafian vesicles in them are very minute, and probably never attain full development, but soon shrivel and disappear, instead of bursting, as matured follicles do; the contained ova are also incapable of being impregnated. But, coincident with the other changes which occur in the body at the time of puberty, the ovaries enlarge, and become very vascular, the formation of Graafian vesicles is more abundant, the size and degree of development attained by them are greater, and the ova are capable of being fecundated.

Fallopian Tubes.—The *Fallopian tubes* are about four inches in length, and extend between the ovaries and the upper angles of the uterus. At the point of attachment to the uterus, the Fallopian tube is very narrow; but in its course to the ovary it increases to about a line and a half in thickness; at its distal extremity, which is free and floating, it bears a number of *fimbriæ,* one of which, longer than the rest, is attached to the ovary. The canal by which each Fallopian tube is traversed is narrow, especially at its point of entrance into the uterus, at which it will scarcely admit a bristle, its other extremity is wider, and opens into the cavity of the abdomen, surrounded by the zone of fimbriæ. Externally, the Fallopian tube is invested with peritoneum; internally, its canal is lined with mucous membrane, covered with ciliated epithelium: between the peritoneal and mucous coats, the walls are composed, like those of the uterus, of fibrous tissue and plain muscular fibres.

Uterus.—The *Uterus* (*u, c,* Fig. 392) is somewhat pyriform, and in the unimpregnated state is about three inches in length, two in breadth at its upper part or *fundus,* but at its lower pointed part or *neck,* only about half an inch. The part between the fundus and neck is termed the *body* of the uterus: it is about an inch in thickness.

Structure.—The uterus is constructed of three principal layers, or coats,—*serous, fibrous* and *muscular,* and *mucous.* (1.) The serous coat, which has the same general structure as the peritoneum, covers the organ before and behind, but is absent from the front surface of the neck. (2.) The middle coat is composed of dense connective tissue, with which are intermingled fibres of unstriped muscle. The latter become enormously developed during pregnancy. (3.) The mucous membrane of the uterus will be described more in detail presently (p. 242, Vol. II.). It is lined by columnar ciliated epithelium, which extends also into the interior of the tubular glands, of which the mucous membrane is largely made up. (Allen Thomson, Nylander, Friedländer, John Williams.)

The cavity of the uterus corresponds in form to that of the organ itself: it is very small in the unimpregnated state; the sides of its mucous surface being almost in contact, and probably only separated from each other by mucus. Into its upper part, at each side, opens the canal of the corresponding Fallopian tube: below, it communicates with the vagina by a fissure-like opening in its neck, the *os uteri*, the margins of which are distinguished into two lips, an anterior and posterior. In the mucous membrane of the cervix are found several mucous follicles, termed ovula or glandulæ Nabothi: they probably form the jelly-like substance by which the os uteri is usually found closed.

The *vagina* is a membranous canal, five or six inches long, extending obliquely downward and forward from the neck of the uterus, which it embraces, to the external organs of generation. It is lined with mucous membrane, which in the ordinary contracted state of the canal is thrown into transverse folds. External to the mucous membrane the walls of the vagina are constructed of fibrous tissue, within which, especially around the lower part of the tube, is a layer of erectile tissue. The lower extremity of the vagina is embraced by an orbicular muscle, the *constrictor vaginæ;* its external orifice, in the virgin, is partially closed by a fold or ring of mucous membrane, termed the *hymen*. The external organs of generation consist of the *clitoris*, a small elongated body, situated above and in the mdidle line, and constructed, like the male penis, of two erectile corpora cavernosa, but unlike it, without a corpus spongiosum, and not perforated by the urethra; of two folds of mucous membrane, termed *labia interna*, or *nymphæ;* and, in front of these, of two other folds, the *labia externa*, or *pudenda*, formed of the external integument, and lined internally by mucous membrane. Between the nymphæ and beneath the clitoris is an angular space, termed the vestibule, at the centre of whose base is the orifice of the *meatus urinarius*. Numerous mucous follicles are scattered beneath the mucous membrane composing these parts of the external organs of generation; and at the side of the lower part of the vagina, are two larger lobulated glands, named *vulvo-vaginal*, or Duverney's glands, which are analogous to Cowper's glands in the male.

Discharge of the Ovum.—In the process of development of individual Graafian vesicles, it has been already observed, that as each increases in size, it gradually approaches the surface of the ovary, and when fully ripe or mature, forms a little projection on the exterior. Coincident with the increase of size, caused by the augmentation of its liquid contents, the external envelope of the distended vesicle becomes very thin and eventually bursts. By this means, the ovum and fluid contents of the Graafian vesicle are liberated, and escape on the exterior of the ovary, whence they pass into the Fallopian tube, the fimbriated processes of the extremity of which are supposed coincidentally to grasp the ovary, while the aperture of the tube is applied to the part corresponding to the matured and bursting vesicle.

In animals whose capability of being impregnated occurs at regular periods, as in the human subject, and most Mammalia, the Graafian vesicles and their contained ova appear to arrive at maturity, and the latter to be discharged at such periods only. But in other animals, *e.g.*, the common fowl, the formation, maturation, and discharge of ova appear to take place almost constantly.

It has long been known, that in the so-called oviparous animals, the separation of ova from the ovary may take place independently of impregnation by the male, or even of sexual union. And it is now established that a like maturation and discharge of ova, independently of coition, occurs in Mammalia, the periods at which the matured ova are separated from the ovaries and received into the Fallopian tubes being indicated in the lower Mammalia by the phenomena of *heat* or *rut:* in the human female, although not always with exact coincidence, by the phenomena of *menstruation*. If the union of the sexes take place, the ovum may be fecundated, and if no union occur it perishes.

That this maturation and discharge occur periodically, and only during the phenomena of heat in the lower Mammalia, is made probable by the facts that, in all instances in which Graafian vesicles have been found presenting the appearance of recent rupture, the animals were at the time, or had recently been, in heat; that on the other hand, there is no authentic and detailed account of Graafian vesicles being found ruptured in the intervals of the period of heat; and that female animals do not admit the males, and never become impregnated, except at those periods.

Menstruation.—Many circumstances make it certain that the human female is subject, in these respects, to the same law as the females of other mammiferous animals; namely, that in her as in them, ova are matured and discharged from the ovary independent of sexual union. This maturation and discharge occur, moreover, periodically at or about the epochs of menstruation. Thus Graafian vesicles recently ruptured have been frequently seen in ovaries of virgins or women who could not have been recently impregnated; and although it is true that the ova discharged under these circumstances have rarely been discovered in the Fallopian tube, partly on account of their minute size, and partly because the search has seldom been prosecuted with much care, yet analogy forbids us to doubt that in the human female, as in the domestic quadrupeds, the result and purpose of the rupture of the follicles is the discharge of the ova.

The evidence of the periodical discharge of ova is that in most cases in which signs of menstruation have been found in the uterus, follicles in a state of maturity or of rupture have been seen in the ovary; and that although conception is not confined to the periods of menstruation, yet it is more likely to occur about a menstrual epoch than at other times.

The exact relation between the discharge of ova and menstruation is not very clear. It was generally believed that the monthly flux was the result of a congestion of the uterus arising from the enlargement and rupture of a Graafian follicle; but though a Graafian follicle is, as a rule, ruptured at each menstrual epoch, yet several instances are recorded in which menstruation has occurred where no Graafian follicle has been ruptured, and on the other hand cases are known where ova have been discharged in amenorrhœic women. It must therefore be admitted that menstruation is not dependent on the maturation and discharge of ova.

It was, moreover, generally understood that ova were discharged toward the close or soon after the cessation of a menstrual flow. Observations made after death, and facts obtained by clinical investigation, however, do not support this view. (Reichert, J. Williams, Löwenthal.) Rupture of a Graafian follicle does not happen on the same day of the monthly period in all women. It may occur toward the close or soon after the cessation of a flow; but only in a small minority of the subjects examined after death was this the case. On the other hand, in almost all such subjects of which there is record, rupture of the follicle appears to have taken place before the commencement of the catamenial flow. Moreover, the custom of the Jews—a prolific race, to whom by the Levitical law sexual intercourse during the week following menstruation was forbidden—militates strongly in favor of the view that conception usually occurs before and not soon after a menstrual epoch, and necessarily, therefore, for the view that ova are usually discharged before the catamenial flow. This, together with the anatomical condition of the uterus just before the catamenia, seem to indicate that the ovum fertilized is that which is discharged in connection with the first absent, and not that with the last present menstruation. (Kundrat.)

Though menstruation does not appear to depend upon the discharge of ova, yet the presence of the ovaries seems necessary for the performance of the function; for women do not menstruate when both ovaries have been removed by operation. Some instances have been recently recorded, indeed, of a sanguineous discharge, occurring periodically from the vagina after both ovaries have been previously removed for disease; and it has been inferred from this that menstruation is a function independent of the ovary: but this evidence is not conclusive, inasmuch as it is possible that portions of ovarian tissue were left after the operation.

Characters of Menstrual Discharge.—The menstrual discharge is a thin sanguineous fluid, having a peculiar odor. It is of a dark color, and consists of blood, epithelium, and mucus from the uterus and vagina, serum, and the débris of a membrane called the *decidua menstrualis.* This membrane is the developed mucous surface of the body of the uterus. It does not extend into the Fallopian tube or into the cavity of the cervix. It attains its highest state of development in the unimpregnated organ just before the commencement of a catamenial flow (Fig. 396). If impregnation take place, it becomes the *decidua vera;* if impregnation fail, the membrane undergoes rapid disintegration; its vessels are laid open and hæmorrhage follows (John Williams). The blood poured out does not coagulate in consequence partly of the admixture already mentioned, or, very possibly, coagulation occurs, but the process is more or less spoiled, and what clot is formed is broken down again, so as to imitate liquid blood. (See also p. 73, Vol. I.)

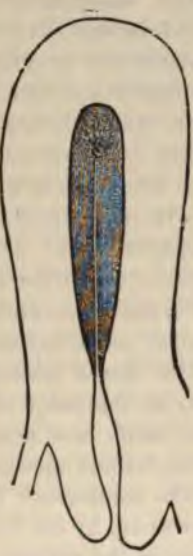


FIG. 396.

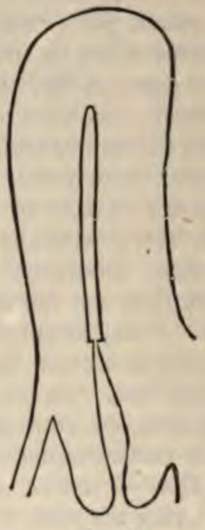


FIG. 397.

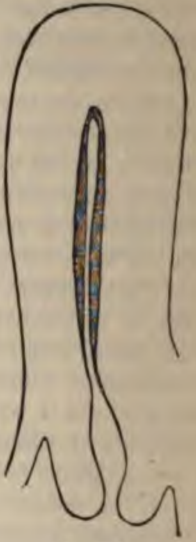


FIG. 398.

FIG. 396.—Diagram of uterus just before menstruation; the shaded portion represents the thickened mucous membrane.

FIG. 397.—Diagram of uterus when menstruation has just ceased, showing the cavity of the uterus deprived of mucous membrane.

FIG. 398.—Diagram of uterus a week after the menstrual flux has ceased: the shaded portion represents renewed mucous membrane. (J. Williams.)

Menstruation, therefore, is not the result of congestion, or of a species of erection, but of a destructive process by which the *decidua* or *nidus* prepared for an impregnated ovum is carried away. It is not a sign of the capability of being impregnated as much as of disappointed impregnation.

The occurrence of a menstrual discharge is one of the most prominent indications of the commencement of puberty in the female sex; though its absence even for several years is not necessarily attended with arrest of the other characters of this period of life, or with inaptness for sexual union, or incapability of impregnation. The average time of its first appearance in females of this country and others of about the same latitude, is from fourteen to fifteen; but it is much influenced by the kind of life to which girls are subjected, being accelerated by habits of luxury and indolence, and retarded by contrary conditions. On the whole, its appearance is earlier in persons dwelling in warm climes than in those inhabiting colder latitudes; though the extensive investigations of Robertson show that the influence of temperature on the development of puberty has been exaggerated. Much of the influence attributed to climate appears due to the custom prevalent in many hot countries, as in Hindostan, of giving girls in marriage at a very early age, and inducing sexual excitement previous to the proper menstrual time. The menstrual functions continue through the whole fruitful period of a woman's life, and usually cease between the forty-fifth and fiftieth years.

The several menstrual periods usually occur at intervals of a lunar month, the duration of each being from three to six days. In some women the intervals are as short as three weeks or even less; while in others they are longer than a month. The periodical return is usually attended by pain in the loins, a sense of fatigue in the lower limbs, and other symptoms, which are different in different individuals. Menstruation does not usually occur in pregnant women, or in those who are suckling; but instances of its occurrence in both these conditions are by no means rare.

Corpus Luteum.

Immediately before, as well as subsequent to, the rupture of a Graafian vesicle, and the escape of its ovum, certain changes ensue in the interior of the vesicle, which result in the production of a yellowish mass, termed a *Corpus luteum.*

When fully formed the corpus luteum of mammiferous animals is a roundish solid body, of a yellowish or orange color, and composed of a number of lobules, which surround, sometimes a small cavity, but more frequently a small stelliform mass of white substance, from which delicate processes pass as septa between the several lobules. Very often, in the cow and sheep, there is no white substance in the centre of the corpus luteum; and the lobules projecting from the opposite walls of the Graafian vesicle appear in a section to be separated by the thinnest possible lamina of semi-transparent tissue.

When a Graafian vesicle is about to burst and expel the ovum, it becomes highly vascular and opaque; and, immediately before the rupture takes place, its walls appear thickened on the interior by a reddish glutinous or fleshy-looking substance. Immediately after the rupture, the inner layer of the wall of the vesicle appears pulpy and flocculent. It is thrown into wrinkles by the contraction of the outer layer, and, soon, red fleshy mammillary processes grow from it, and gradually enlarge till they nearly fill the vesicle, and even protrude from the orifice in the external covering of the ovary. Subsequently this orifice closes, but the fleshy growth within still increases during the earlier period of pregnancy, the color of the substance gradually changing from red to yellow, and its consistence becoming firmer.

The corpus luteum of the human female (Fig. 399) differs from that of the domestic quadruped in being of a firmer texture, and having more frequently a persistent cavity at its centre, and in the stelliform cicatrix, which remains in the cases where the cavity is obliterated, being proportionately of much larger bulk. The quantity of yellow substance formed is also much less: and, although the deposit increases after the vesicle has burst, yet it does not usually form mammillary growths projecting into the cavity of the vesicle, and never protrudes from the orifice, as is the case in other Mammalia. It maintains the character of a uniform, or nearly uniform, layer, which is thrown into wrinkles, in consequence of the contraction of the external tunic of the vesicle. After the orifice of the vesicle has closed, the growth of the yellow substance continues during the first half of pregnancy, till the cavity is reduced to a comparatively small size, or is obliterated; in the latter case, merely a white stelliform cicatrix remains in the centre of the corpus luteum.

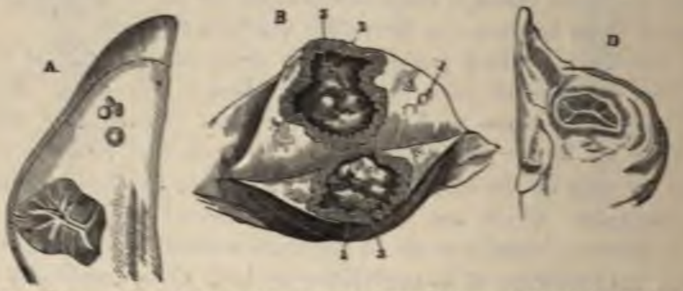


FIG. 399.—Corpora lutea of different periods. B, Corpus luteum of about the sixth week after impregnation, showing its plicated form at that period. 1, substance of the ovary; 2, substance of the corpus luteum; 3, a greyish coagulum in its cavity. (Peterson.) A, corpus luteum two days after delivery; D, in the twelfth week after delivery. (Montgomery.)

An effusion of blood generally takes place into the cavity of the Graafian vesicle at the time of its rupture, especially in the human subject, but it has no share in forming the yellow body; it gradually loses its coloring matter, and acquires the character of a mass of fibrin. The serum of the blood sometimes remains included within a cavity in the centre of the coagulum, and then the decolorized fibrin forms a membraniform sac, lining the corpus luteum. At other times the serum is removed, and the fibrin constitutes a solid stelliform mass.

The yellow substance of which the corpus luteum consists, both in the human subject and in the domestic animals, is a growth from the inner surface of the Graafian vesicle, the result of an increased development of the cells forming the membrana granulosa, which naturally lines the internal tunic of the vesicle.

The first changes of the internal coat of the Graafian vesicle in the process of formation of a corpus luteum, seem to occur in every case in which an ovum escapes; as well in the human subject as in the domestic quadrupeds. If the ovum is impregnated, the growth of the yellow substance continues during nearly the whole period of gestation, and forms the large corpus luteum commonly described as a characteristic mark of impregnation. If the ovum is not impregnated, the growth of yellow substance on the internal surface of the vesicle proceeds, in the human ovary, no further than the formation of a thin layer, which shortly disappears; but in the domestic animals it continues for some time after the ovum has perished, and forms a corpus luteum of considerable size. The fact that a structure, in its essential characters similar to, though smaller than, a corpus luteum observed during pregnancy, is formed in the human subject, independent of impregnation or of sexual union, coupled with the varieties in size of corpora lutea formed during pregnancy, necessarily renders unsafe all evidence of previous impregnation founded on the existence of a corpus luteum in the ovary.

The following table by Dalton, expresses well the differences between the corpus luteum of the pregnant and unimpregnated condition respectively.

	Corpeus Luteum of Menstruation	Corpus Luteum of Pregnancy.
At the end of three weeks.	Three-quarters of an inch in diameter; central clot reddish; convoluted wall pale.	
One month . .	Smaller; convoluted wall bright yellow; clot still reddish.	Larger; convoluted wall bright yellow; clot still reddish.
Two months .	Reduced to the condition of an insignificant cicatrix.	Seven-eighths of an inch in diameter; convoluted wall bright yellow; clot perfectly decolorized.
Six months . .	Absent.	Still as large as at end of second month; clot fibrinous; convoluted wall paler.
Nine months .	Absent.	One-half an inch in diameter; central clot converted into a radiating cicatrix; the external wall tolerably thick and convoluted, but without any bright yellow color.

IMPREGNATION OF THE OVUM.

MALE SEXUAL FUNCTIONS.

Testes.—The fluid of the male, by which the ovum is impregnated, consists essentially of the semen secreted by the *testicles:* and to this are added, as necessary, perhaps, to its perfection, a material secreted by the *vesiculæ seminales,* as well as the secretion of the prostate gland, and of Cowper's glands. Portions of these several fluids are, probably, all discharged, together with the proper secretion of the testicles.

The secreting structure of the testicle and its duct are disposed of in two contiguous parts, (1) the body of the testicle enclosed within a tough fibrous membrane, the *tunica albuginea,* on the outer surface of which is the serous covering formed by the *tunica vaginalis,* and (2) the *epididymis* and *vas deferens.*

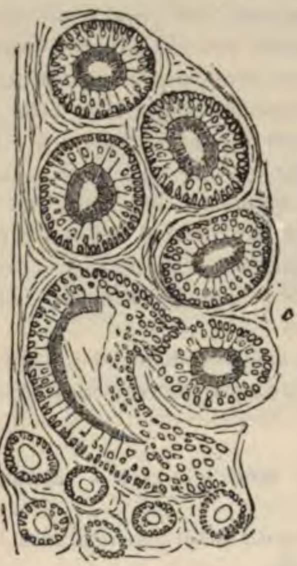


FIG. 400.

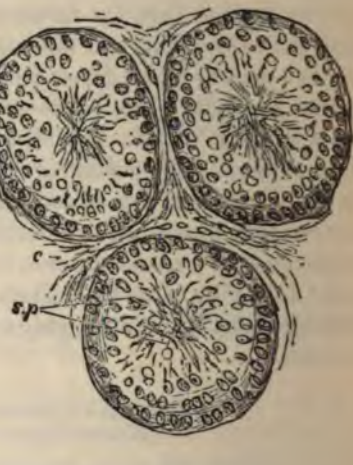


FIG. 401.

FIG. 400.—Section of a dog's epididymis. The tube is cut in several places, both transversely and obliquely; it is seen to be lined by a ciliated epithelium, the nuclei of which are well shown. *c,* connective tissue. (Schofield.)

FIG. 401.—A section of dog's testicle, highly magnified, showing three "tubuli seminiferi," lined and largely occupied by a spheroidal epithelium, the numerous nuclei of which are well seen; *c,* connective tissue surrounding and supporting the tubuli; *sp,* masses of spermatozoa occupying the centre of tubuli: the small black bodies scattered about are the heads of the spermatozoa. (Schofield.)

Vas Deferens.—The *vas deferens,* or duct of the testicle, which is about two feet in length, is constructed externally of connective tissue, and internally is lined by mucous membrane, covered by columnar epithelium; while between these two coats is a middle coat, very firm and tough, made up chiefly of longitudinal with some circular plain muscular fibres. When followed back to its origin, the vas deferens is found to pass to the lower part of the *epididymis*, with which it is directly continuous (Fig. 402), and assumes there a much smaller diameter with an exceedingly tortuous course.

The *epididymis*, which is lined, except at its lowest part, by columnar ciliated epithelium (Fig. 400), is commonly described as consisting (Fig. 402) of a *globus minor* (*g*), the *body* (*e*), and the *globus major* (*l*). When unraveled, it is found to be constructed of a single tube, measuring about twenty feet in length.

At the globus major this duct divides into ten or twelve small branches, the convolutions of which form coniform masses, named *coni vasculosi;* and the ducts continued from these, the *vasa efferentia*, after anastomosing, one with another, in what is called the *rete testis*, lead finally as the *tubuli recti* or *vasa recta* to the *tubules* which form the proper substance of the testicle, wherein they are arranged in lobules, closely packed, and all attached to the tough fibrous tissue at the back of the testicle. The epithelium of the coni vasculosi and vasa efferentia is columnar and ciliated; that of the rete testis is squamous.

Structure of Seminal Tubes.—The seminal tubes, or *tubuli seminiferi*, which compose the parenchyma of the testicle, are arranged in lobules between the connective tissue septa.

They are relatively large, very wavy, and much convoluted; and they possess a few lateral branches, by which they become connected into a network. They form terminal loops, and in the peripheral portion of the testis the tubules are possessed of minute lateral cæcal branchlets.

Each seminal tubule in the adult testis is limited by a membrana propria, which appears as a hyaline elastic membrane containing oval flattened nuclei at regular intervals. Inside this membrana propria are several layers of epithelial cells, the *seminal cells*. These consist of an inner and outer layer, the latter being situated next the membrana propria. These cells are of two kinds, those that are in a resting state and those that are in a state of division. The latter are called mother cells, and the smaller cells resulting from their division are called daughter cells or spermatoblasts. From these the spermatozoa are formed. During their development they lie in groups, but when fully formed they become detached and fill the lumen of the seminiferous tubule (Fig. 401).

Spermatozoa.—On examining the spermatozoon of Triton cristatus, one of the Amphibia which possess the largest of all Vertebrate animals, Heneage Gibbes found that the organism (Fig. 404) consisted of (*a*) a long pointed head, at the base of which is (*b*), an elliptical structure joining the head to (*c*), a long filiform body; (*d*), a fine filament, much longer than the body, is connected with this latter by (*e*), a homogeneous membrane.

The head, as it appears in the fresh specimen, has a different refractive power from that of the rest of the organism, and with a high power appears to be a light green color; there is also a central line running up it, from which it appears to be hollow. The elliptical structure at the base of the head connects it with the long thread-like body, and the filament springs from it. Whilst the spermatozoon is living, this filament is in constant motion; at first this is so quick that it is difficult to see it, but as its vitality becomes impaired the motion gets slower, and it is then easily perceived to be a continuous waving from side to side.

In Man the head (Fig. 405) is club-shaped, and from its base springs the very delicate filament which is three or four times as long as the body; and the membrane which attaches it to the body is much broader, and allows it to lie at a greater distance from the body than in the spermatozoa of any other Mammal examined.

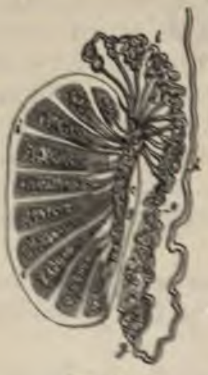


FIG. 402.

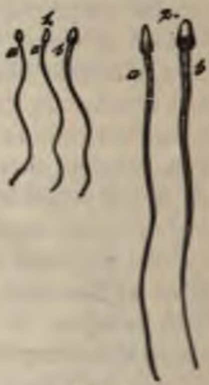


FIG. 403.

FIG. 402.—Plan of a vertical section of the testicle, showing the arrangement of the ducts. The true length and diameter of the ducts have been disregarded. *a, a*, tubuli seminiferi coiled up in the separate lobes; *b*, tubuli recti or vasa recta; *c*, rete testis; *d*, vasa efferentia ending in the coni vasculosi; *l, e, g*, convoluted canal of the epididymis; *h*, vas deferens; *f*, section of the back part of the tunica albuginea; *i, i*, fibrous processes running between the lobes; *s*, mediastinum.

FIG. 403.—Spermatic filaments from the human vas deferens. 1, magnified 350 diameters; 2, magnified 800 diameters; *a*, from the side; *b*, from above. (From Kölliker.)

Gibbes concludes:—1st. That the head of the spermatozoon is enclosed in a sheath, which is a continuation of the membrane which surrounds the filament and connects it to the body, acting in fact the part of a mesentery. 2ndly. That the substance of the head is quite distinct in its composition from the elliptical structure, the filament and the long body, and that it is readily acted upon by alkalies; these re-agents have no effect, however, on the other part, excepting the membranous sheath. 3rdly. That this elliptical structure has its analogue in the Mammalian spermatozoon; in the one case the head is drawn out as a long pointed process, in the other it is of a globular form, and surrounds the elliptical structure. 4thly. That the motive power lies, in a great measure, in the filament and the membrane attaching it to the body.

The occurrence of spermatozoa in the impregnating fluid of nearly all classes of animals proves that they are essential to the process of impregnation, and their actual contact with the ovum is necessary for its development; but concerning the manner of their action nothing is known.

The seminal fluid is, probably, after the period of puberty, secreted constantly, though, except under excitement, very slowly, in the tubules of the testicles. From these, it passes along the vasa deferentia into the vesiculæ seminales, whence, if not expelled in emission, it may be discharged, as slowly as it enters them, either with the urine, which may remove minute quantities, mingled with the mucus of the bladder and the secretion of the prostate, or from the urethra in the act of defæcation.

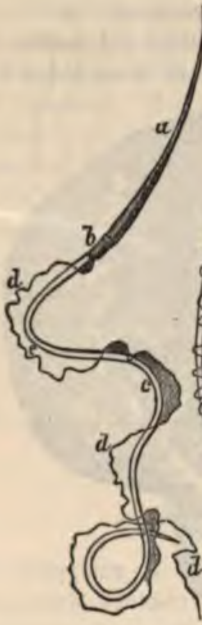


FIG. 404.

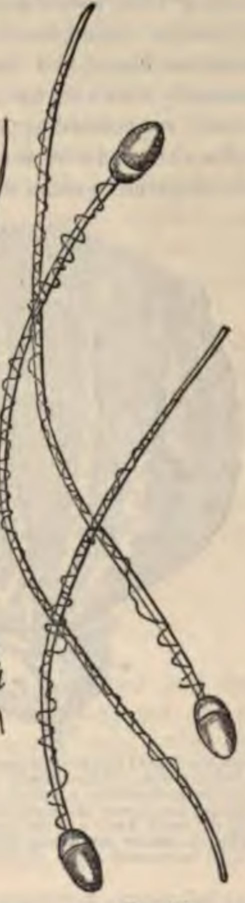


FIG. 405.

FIG. 404.—Spermatozoon of Salamandra Maculata. Fresh mounted in glycerin. × 950, reduced one half.

FIG. 405.—Human Spermatozoa. × 2500. (H. Gibbes.)

Vesiculæ Seminales.—The *vesiculæ seminales* (Fig. 406) have the appearance of outgrowths from the vasa deferentia. Each vas deferens, just before it enters the prostate gland, through part of which it passes to terminate in the urethra, gives off a side-branch, which bends back from it at an acute angle: and this branch dilating, variously branching, and pursuing in both itself and its branches a tortuous course, forms the vesicula seminalis.

Structure.—Each of the vesiculæ, therefore, might be unraveled into a single branching tube, sacculated, convoluted, and folded up. The structure of the vesiculæ resembles closely that of the vasa deferentia. The mucous membrane lining the vesiculæ seminales, like that of the gall-bladder, is minutely wrinkled and set with folds and ridges arranged so as to give it a finely reticulated appearance.

Functions.—To the vesiculæ seminales a double function may be assigned; for they both secrete some fluid to be added to that of the testicles, and serve as reservoirs for the seminal fluid. The former is their most constant and probably most important office; for in the horse, bear, guinea-pig, and several other animals, in whom the vesiculæ seminales are large and of apparently active function, they do not communicate with the vasa deferentia, but pour their secretions, separately, though it may be simultaneously, into the urethra. In man, also, when one testicle is lost, the corresponding vesicula seminalis suffers no atrophy, though its function as a reservoir is abrogated. But how the vesiculæ seminales act as secreting organs is unknown; the peculiar brownish fluid which they

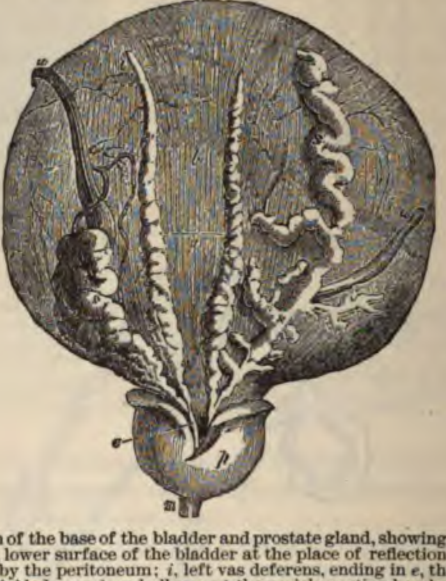


FIG. 406.—Dissection of the base of the bladder and prostate gland, showing the vesiculæ seminales and vasa deferentia. *a*, lower surface of the bladder at the place of reflection of the peritoneum; *b*, the part above covered by the peritoneum; *i*, left vas deferens, ending in *e*, the ejaculatory duct; the vas deferens has been divided near *i*, and all except the vesicle portion has been taken away; *s*, left vesicula seminalis joining the same duct; *s*, *s*, the right vas deferens and right vesicula seminalis, which has been unraveled; *p*, under side of the prostate gland; *m*, part of the urethra; *u*, *u*, the ureters (cut short), the right one turned aside. (Haller.)

contain after death does not properly represent their secretion, for it is different in appearance from anything discharged during life, and is mixed with semen. It is nearly certain, however, that their secretion contributes to the proper composition of the impregnating fluid; for in all the animals in whom they exist, and in whom the generative functions are exercised at only one season of the year, the vesiculæ seminales, whether they communicate with the vasa deferentia or not, enlarge commensurately with the testicles at the approach of that season.

That the vesiculæ are also reservoirs in which the seminal fluid may lie for a time previous to its discharge, is shown by their commonly containing the seminal filaments in larger abundance than any portion of the seminal ducts themselves do. The fluid-like mucus, also, which is often discharged from the vesiculæ in straining during defæcation, commonly contains seminal filaments. But no reason can be given why this office of the vesiculæ should not be equally necessary to all the animals whose testicles are organized like those of man, or why in many animals the vesiculæ are wholly absent.

There is an equally complete want of information respecting the secretions of the prostate and Cowper's glands, their nature and purposes. That they contribute to the right composition of the impregnating fluid, is shown both by the position of the glands and by their enlarging with the testicles at the approach of an animal's breeding time. But that they contribute only a subordinate part is shown by the fact, that, when the testicles are lost, though these other organs be perfect, all procreative power ceases.

THE SEMEN.

The mingled secretions of all the organs just described, form the *semen*, which is a thick whitish fluid composed of a *liquor seminis* and *spermatozoa*, with detached epithelial cells. The fluid part has not been satisfactorily analyzed: but Henle says it contains fibrin, because shortly after being discharged, flocculi form in it by spontaneous coagulation, and leave the rest of it thinner and more liquid, so that the filaments move in it more actively.

Nothing has shown what it is that makes this fluid with its corpuscles capable of impregnating the ovum, or (what is yet more remarkable) of giving to the developing offspring all the characters, in features, size, mental disposition, and liability to disease, which belong to the father. This is a fact wholly inexplicable: and is, perhaps, only exceeded in strangeness by those facts which show that the seminal fluid may exert such an influence, not only on the ovum which it impregnates, but, through the medium of the mother, on many which are subsequently impregnated by the seminal fluid of another male.

It has been often observed that a well-bred bitch, if she have been once impregnated by a mongrel dog, will not bear thorough-bred puppies in the next two or three litters after that succeeding the copulation with the mongrel. But the best instance of the kind was in the case of a mare belonging to Lord Morten, who, while he was in India, wished to obtain a cross-breed between the horse and the quagga, and caused this mare to be covered by a male quagga. The foal that she next bore had the distinct marks of the quagga, in the shape of its head, black bars on the legs and shoulders, and other characters. After this time she was thrice covered by horses, and every time the foal she bore had still distinct, though decreasing, marks of the quagga; the peculiar characters of the quagga being thus impressed not only on the ovum then impregnated, but on the three following ova impregnated by horses. It would appear, therefore, that the constitution of an impregnated female may become so altered and tainted with the peculiarities of the impregnating male, through the medium of the fœtus, that she necessarily imparts such peculiarities to any offspring she may subsequently bear by other males. Of the direct means by which a peculiarity of structure on the part of a male is thus transmitted, nothing whatever is known.

As bearing upon this subject, the following note kindly given to the Editors by Mr. S. Probart may be added:—On the Farm Wellwood, the property of Charles R——, Esq., in the Division of Graaff Remet, Cape of Good Hope, there is at present running an aged mare with a numerous progeny. Some years ago she foaled for three successive seasons to a donkey; after that she gave birth to a mare foal, to a horse. This filly was a chestnut, and did not exhibit any taint of the donkey by which her dam had previously foaled. But when *she* in her turn foaled to a horse, *her* young bore the distinct marks along the back and withers, and rings round the lower parts of the legs, which are the peculiarity of the ass and the mule. Three foals she has had are all so marked.

DEVELOPMENT.—CHANGES IN THE OVUM UP TO FORMATION OF THE BLASTODERM.

The earlier stages in development are so fundamentally similar in all vertebrate animals, from Fishes up to Man, that the gaps existing in our knowledge of the process in the higher Mammalia, such as man, may be in part, at any rate, filled up by the more accurate knowledge which we possess of the development of the ovum in such animals as the trout, frog, and fowl.

One important distinction between the ova of various Vertebrata should be remembered. In the hen's egg, besides the shell and the white or albumen, two other structures are to be distinguished—the *germ*, often called the cicatricula or "tread," and the *yelk* enclosed in its vitelline membrane.

The *germ* is essentially a cell, consisting of protoplasm enclosed in a nucleus and nucleolus. It alone participates in the process of *segmentation* (to be immediately described), the great mass of the yelk (food-yelk) remaining quite unaffected by it. Since only the germ, which forms but a small portion of the yelk, undergoes segmentation, the ovum is called *meroblastic*.

In the Mammalia, on the other hand, there is no large unsegmented mass corresponding to the food-yelk of birds; the entire ovum undergoes segmentation, and is hence termed *holoblastic.*

The eggs of Fishes, Reptiles, and Birds, are meroblastic, while those of Amphibia and Mammalia are holoblastic.

Of the changes which the mammalian ovum undergoes previous to the formation of the embryo, some occur while it is still in the ovary, and are apparently independent of impregnation: others take place after it has reached the Fallopian tube. The knowledge we possess of these changes is derived almost exclusively from observations on the ova of the bitch and rabbit: but it may be inferred that analogous changes ensue in the human ovum.

Bischoff describes the yelk of an ovarian ovum soon after coitus as being unchanged in its characters, with the single exception of being fuller and more dense; it is still granular, as before, and does not possess any of the cells subsequently found in it. The germinal vesicle always disappears, sometimes before the ovum leaves the ovary, at other times not until it has entered the Fallopian tube; but always before the commencement of the metamorphosis of the yelk.

As the ovum approaches the middle of the Fallopian tube, it begins to receive a new investment, consisting of a layer of transparent albuminous or glutinous substance, which forms upon the exterior of the zona pellucida. It is at first exceedingly fine, and, owing to this, and to its transparency, is not easily recognized: but at the lower part of the Fallopian tube it acquires considerable thickness.

Segmentation.—The first visible result of fertilization is a slight amœboid movement in the protoplasm of the ovum: this has been observed in some fish, in the frog, and in some mammals. Immediately succeeding to this the process of *segmentation* commences, and is completed during the passage of the ovum through the Fallopian tube. The yelk becomes constricted in the middle, and surrounded by a furrow which, gradually deepening, at length cuts the yelk in half while the same process begins almost immediately in each half of the yelk, and cuts it also in two. The same process is repeated in each of the quarters, and so on, until at last by continual cleavings the whole yelk is changed into a mulberry-like mass of small and more or less rounded bodies, sometimes called "vitelline spheres," the whole still enclosed by the *zona pellucida* or *vitelline membrane* (Fig. 406*). Each of these little spherules contains a transparent vesicle like an oil-globule, which is seen with difficulty on account of its being enveloped by the yelk-granules which adhere closely to its surface.

The cause of this singular subdivision of the yelk is quite obscure: though the immediate agent in its production seems to be the central vesicle contained in each division of the yelk. Originally there was probably but one vesicle, situated in the centre of the entire granular mass of the yelk, and probably derived from the germinal vesicle. This divides and subdivides: each successive division and subdivision of the vesicle being accompanied by a corresponding division of the yelk.

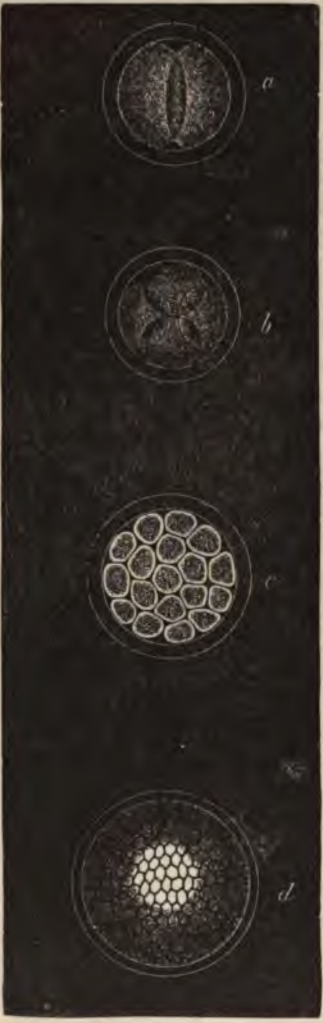


FIG. 406*.—Diagrams of the various stages of cleavage of the yelk (Dalton).

About the time at which the Mammalian ovum reaches the uterus, the process of division and subdivision of the yelk appears to have ceased, its substance having been resolved into its ultimate and smallest divisions, while its surface presents a uniform finely-granular aspect, instead of its late mulberry-like appearance. The ovum, indeed, appears at first sight to have lost all trace of the cleaving process, and, with the exception of being paler and more translucent, almost exactly resembles the ovarian ovum, its yelk consisting apparently of a confused mass of finely granular substance. But on a more careful examination, it is found that these granules are aggregated into numerous minute spheroidal masses, each of which contains a clear vesicle or nucleus in its centre, and is, in fact, an "embryonal cell." The zona pellucida, and the layer of albuminous matter surrounding it, have at this time the same character as when at the lower part of the Fallopian tube.

The passage of the ovum, from the ovary to the uterus, occupies probably eight or ten days in the human female.

When the peripheral cells, which are formed first, are fully developed, they arrange themselves at the surface of the yelk into a kind of membrane, and at the same time assume a polyhedral shape from mutual pressure, so as to resemble pavement epithelium. The deeper cells of the interior pass gradually to the surface and accumulate there, thus increasing the thickness of the membrane already formed by the more superficial layer of cells, while the central part of the yelk remains filled only with a clear fluid. By this means the yelk is shortly converted into a kind of secondary vesicle, the walls of which are composed externally of the original vitelline membrane, and within by the newly formed cellular layer, the *blastodermic* or *germinal* membrane, as it is called.

Layers of the Blastoderm.—Before long the blastoderm is found to consist of three fundamental layers, *Epiblast*, *Mesoblast*, and *Hypoblast*.

The way in which these are formed may be readily studied in a hen's egg. In a freshly laid hen's egg, before incubation has commenced, the blastoderm is found to consist of two layers (Fig. 407, *S* and *D*), the upper of which forms a distinct membrane of columnar cells, while the lower stratum consists of larger cells irregularly arranged.

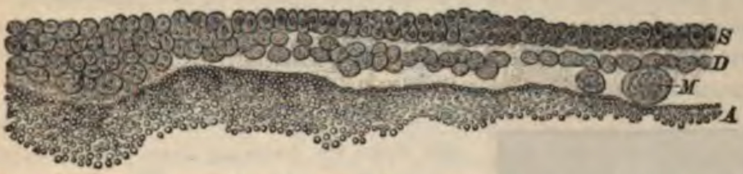


FIG. 407.—Vertical section of area pellucida, and area opaca (left extremity of figure) of blastoderm of a fresh-laid egg (unincubated). *S*, superficial layer corresponding to epiblast; *D*, deeper layer, corresponding to hypoblast, and probably in part to mesoblast; *M*, large "formative cells," filled with yelk granules, and lying on the floor of the segmentation cavity; *A*, the white yelk immediately underlying the segmentation cavity (Stricker).

Beneath the blastoderm there are a few scattered larger cells—"formative cells." In the lower of the above two layers, some cells become flattened and unite to form a distinct membrane (hypoblast); the remaining cells of the lower layer, together with some of the large formative cells, which migrate by amœboid movement round the edge of the hypoblast (Fig. 408, M), constitute a third layer (mesoblast).

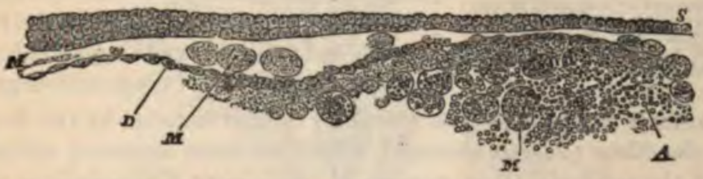


FIG. 408.—Vertical section of blastoderm of chick (1st day of incubation). *S*, epiblast, consisting of short columnar cells; *D*, hypoblast, consisting of a single layer of flattened cells; *M*, "formative cells." They are seen on the right of the figure, passing in between the epiblast and hypoblast to form the mesoblast; *A*, white yelk granules. Many of the large "formative cells" are seen containing these granules (Stricker).

These important changes are among the earliest results of incubation.

From the *epiblast* are ultimately developed the epidermis and its various appendages, also the cerebro-spinal *nerve-centres*, the sensorial epithelium of the organs of special sense (eye, ear, nose), and the epithelium of the mouth and salivary glands.

From the *hypoblast* is developed the epithelium of the whole digestive canal, together with that lining the ducts of all the glands which open into it; also the glandular parenchyma of the glands (*e.g.*, liver and pancreas) connected with it, and the epithelium of the respiratory track.

From the *mesoblast* are derived all the tissues and organs of the body intervening between these two, the whole group of the connective tissues, the muscles and the cerebro-spinal and sympathetic *nerves*, with the vascular and genito-urinary systems, and all the digestive canal with its various appendages with the exception of the lining epithelium above mentioned.

FIRST RUDIMENTS OF THE EMBRYO AND ITS CHIEF ORGANS

Germinal Area.—The position in which the embryo is about to appear is early marked out by a central roundish opacity in the blastoderm, due to the accumulation of cells in this region. This *germinal area*, which is at first circular, changes its shape, becoming pyriform, and finally an elongated oval constricted in the middle like a savoy biscuit.

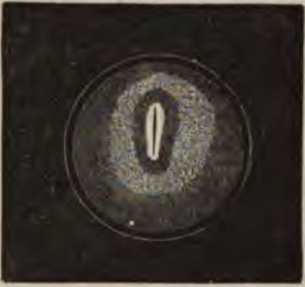


FIG. 409.—Impregnated egg, with commencement of formation of embryo: showing the area germinativa or embryonic spot, the area pellucida, and the primitive groove or trace (Dalton).

The central portion becomes transparent, and thus we have an *area pellucida*, surrounded by an *area opaca* (Fig. 409).

Primitive Groove.—The first trace of the embryo is a shallow longitudinal groove (*primitive groove*), which appears toward the posterior part of the area pellucida (Figs. 409, 412).

Medullary Groove.—The primitive groove is but transitory, and is soon displaced by the *medullary groove*, which first appears at the anterior extremity of the future embryo, and grows backward, gradually causing the disappearance of the primitive groove.

Laminæ dorsales.—The medullary canal is bounded by two longitudinal elevations (*laminæ dorsales*), which are folds consisting entirely of cells of the epiblast: these grow up and arch over the medullary groove (Fig. 411) till they coalesce in the middle line, converting it from an open furrow into a closed tube—the primitive cerebro-spinal axis. Over this closed tube, the walls of which consist of more or less cylindrical cells, the superficial layer of the epiblast is now continued as a distinct membrane.

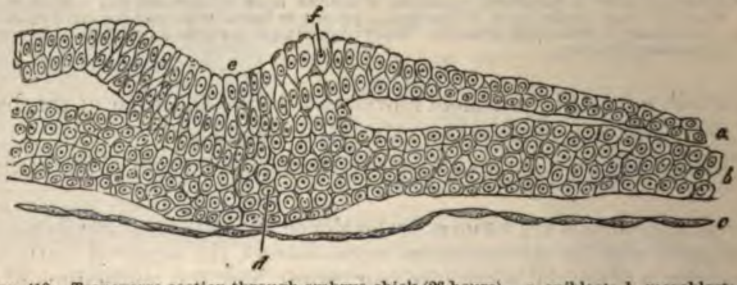


FIG. 410.—Transverse section through embryo chick (26 hours). *a*, epiblast; *b*, mesoblast; *c*, hypoblast; *d*, central portion of mesoblast, which is here fused with epiblast; *e*, primitive groove; *f*, dorsal ridge (Klein).

The union of the medullary folds or laminæ dorsales takes place first about the neck of the future embryo; they soon after unite over the region of the head, while the closing in of the groove progresses much more slowly toward the hinder extremity of the embryo. The medullary groove is by no means of uniform diameter throughout, but even before the dorsal laminæ have united over it, is seen to be dilated at the anterior extremity and obscurely divided by constrictions into the three primary vesicles of the brain.

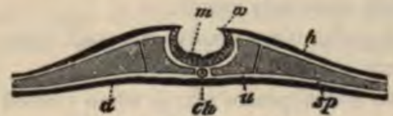


FIG. 411.—Diagram of transverse section through an embryo before the closing-in of the medullary groove. *m*, cells of epiblast lining the medullary groove which will form the spinal cord; *h*, epiblast; *d*, hypoblast; *ch*, notochord; *u*, protovertebra; *sp*, mesoblast; *w*, edge of lamina dorsalis, folding over medullary groove. (Kölliker.)

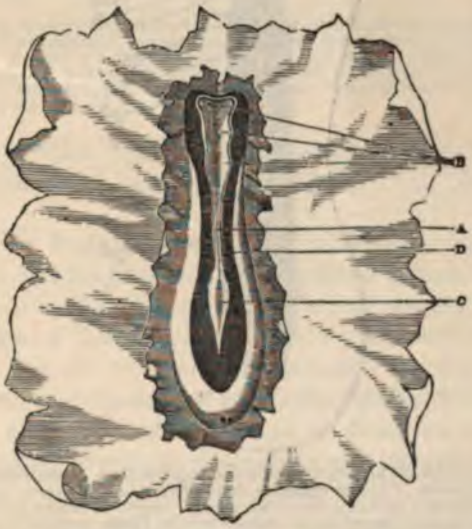


FIG. 412.—Portion of the germinal membrane, with rudiments of the embryo; from the ovum of a bitch. The primitive groove, A, is not yet closed, and at its upper or cephalic end presents three dilatations, B, which correspond to the three divisions or vesicles of the brain. At its lower extremity the groove presents a lancet-shaped dilatation (sinus rhomboidalis) C. The margins of the groove consist of clear pellucid nerve-substance. Along the bottom of the groove is observed a faint streak, which is probably the chorda dorsalis. D, Vertebral plates. (Bischoff.)

The part from which the spinal cord is formed is of nearly uniform calibre, while toward the posterior extremity is a lozenge-shaped dilatation, which is the last part to close in (Fig. 412).

Notochord.—At the same time there appears in the middle line, immediately beneath the floor of the medullary groove, a rod-shaped structure formed by an aggregation of cells of the mesoblast; it soon becomes quite distinct from the remainder of the mesoblast, and constitutes an axial cord (notochord, *chorda dorsalis*) (*ch*, Fig. 414) which extends nearly the whole length of the medullary canal, terminating anteriorly beneath the middle one of the three cerebral vesicles, and occupies the future position of the *bodies* of the vertebræ and basis cranii.

Protovertebræ.—Simultaneously on each side of the notochord appears a longitudinal thickening of the mesoblast.

Thus we have two lateral plates which when viewed from above are seen to be divided into a number of squarish segments (*protovertebræ*) by the formation of transverse clefts. The first three or four of these protovertebræ make their appearance in the cervical region, while one or two more are formed in front of this point: and the series is continued backward till the whole medullary canal is flanked by them (Fig. 413).

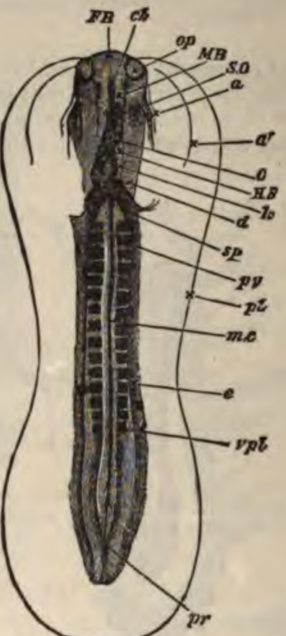


FIG. 413.—Embryo chick (36 hours), viewed from beneath as a transparent object (magnified). *pl*, outline of pellucid area; *FB*, fore-brain, or first cerebral vesicle: from its sides project *op*, the optic vesicles; *SO*, backward limit of somatopleure fold, "tucked in" under head; *a*, headfold of true amnion; *a'*, reflected layer of amnion, sometimes termed "false amnion"; *sp*, backward limit of splanchnopleure folds, along which run the omphalomesaraic veins uniting to form *h*, the heart, which is continued forward into *ba*, the bulbus arteriosus; *d*, the fore-gut, lying behind the heart, and having a wide crescentic opening between the splanchnopleure folds; *HB*, hind-brain; *MB*, mid-brain; *pv*, protovertebræ lying behind the fore-gut; *mc*, line of junction of medullary folds and of notochord; *ch*, front end of notochord; *vpl*, vertebral plates; *pr*, the primitive groove at its caudal end. (Foster and Balfour.)

Splitting of the Mesoblast.—External to the protovertebræ, the mesoblast now splits into two laminæ (*parietal* and *visceral*): of these the former, when traced out from the central axis, is seen to be in close apposition with the epiblast and gives origin to the parietes of the trunk, while the latter adheres more or less closely to the hypoblast, and gives rise to the serous and muscular walls of the alimentary canal and several other parts (Fig. 414).

The united *parietal* layer of the mesoblast with the epiblast is termed *Somatopleure,* the united *visceral* layer and hypoblast, *Splanchnopleure.*

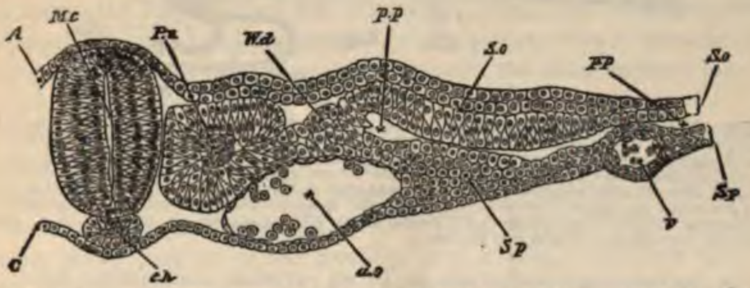


FIG. 414.—Transverse section through dorsal region of embryo chick (45 hours). One half of the section is represented: if completed it would extend as far to the left as to the right of the line of the medullary canal (*Mc*). *A*, epiblast; *C*, hypoblast, consisting of a single layer of flattened cells; *Mc*, medullary canal; *Pv*, protovertebræ; *Wd*, Wolffian duct; *So*, somatopleure; *Sp*, splanchnopleure; *pp*, pleuro-peritoneal cavity; *ch*, notochord; *ao*, dorsal aorta. containing blood-cells; *v*, blood-vessels of the yolk-sac. (Foster and Balfour.)

The space between them is the pleuro-peritoneal cavity, which becomes subdivided by subsequent partitions into pericardium, pleura, and peritoneum.

Head and Tail Folds. Body Cavity.—Every vertebrate animal consist essentially of a longitudinal axis (vertebral column) with a neural canal above it, and a body-çavity (containing the alimentary canal) beneath.

We have seen how the earliest rudiments of the central axis and the neural canal are formed; we must now consider how the general body-cavity is developed. In the earliest stages the embryo lies flat on the surface of the yelk, and is not clearly marked off from the rest of the blastoderm: but gradually a crescentic depression (with its concavity backward) is formed in the blastoderm, limiting the head of the embryo; the blastoderm is, as it were, tucked in under the head, which thus comes to project above the general surface of the membrane: a similar tucking in of blastoderm takes place at the caudal extremity, and thus the head and tail folds are formed (Fig. 415).

Similar depressions mark off the embryo laterally, until it is completely surrounded by a sort of moat which it overhangs on all sides, and which clearly defines it from the yelk.

This moat runs in further and further all round beneath the overhanging embryo, till the latter comes to resemble a canoe turned upside-down, the ends and middle being, as it were, decked in by the folding or tucking in of the blastoderm, while on the ventral surface there is still a large communication with the yelk, corresponding to the "well" or undecked portion of the canoe.

This communication between the embryo and the yelk is gradually contracted by the further tucking in of the blastoderm from all sides, till it become narrowed down, as by an invisible constricting band, to a mere pedicle which passes out of the body of the embryo at the point of the future umbilicus.

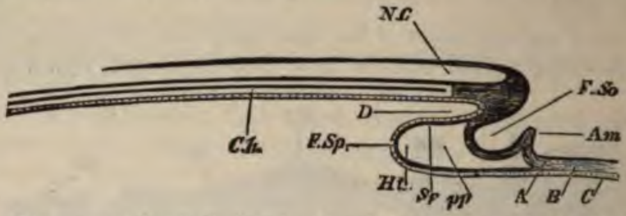


FIG. 415.—Diagrammatic longitudinal section through the axis of an embryo. The head-fold has commenced, but the tail-fold has not yet appeared. *FSo*, fold of the somatopleure; *FSp*, fold of the splanchnopleure; the line of reference, *FSo*, lies outside the embryo in the "moat," which marks off the overhanging head from the amnion; *D*, inside the embryo, is that part which is to become the fore-gut; *FSo* and *FSp*, are both parts of the head-fold, and travel to the left of the figure as development proceeds; *pp*, space between somatopleure and splanchnopleure, pleuro-peritoneal cavity; *Am*. commencing head-fold of amnion; *NC*, neural canal; *Ch*, notochord; *Ht*, heart; *A*, *B*, *C*, epiblast, mesoblast, hypoblast. (Foster and Balfour.)

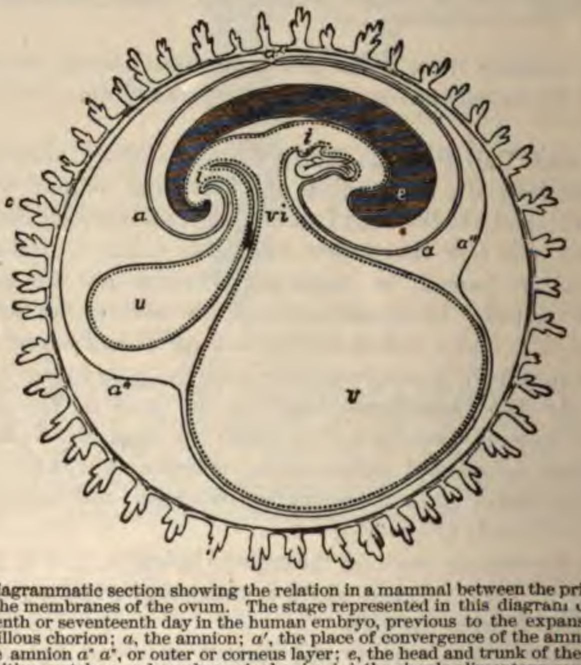


FIG. 416.—Diagrammatic section showing the relation in a mammal between the primitive alimentary canal and the membranes of the ovum. The stage represented in this diagram corresponds to that of the fifteenth or seventeenth day in the human embryo, previous to the expansion of the allantois; *c*, the villous chorion; *a*, the amnion; a', the place of convergence of the amnion and reflexion of the false amnion a'' a'', or outer or corneus layer; *e*, the head and trunk of the embryo, comprising the primitive vertebræ and cerebro-spinal axis; *i*, *i*, the simple alimentary canal in its upper and lower portions. Immediately beneath the right hand *i*, is seen the fœtal heart, lying in the anterior part of the pleuro-peritoneal cavity; *v*, the yolk-sac, or umbilical vesicle; *v i*, the vitello-intestinal opening; *u*, the allantois connected by a pedicle with the anal portion of the alimentary canal. (From Quain's "Anatomy.")

Visceral Plates.—The downwardly folded portions of blastoderm are termed the *visceral plates*.

Thus we see that the body-cavity is formed by the downward folding of the visceral plates, just as the neural cavity is produced by the upward growth of the dorsal laminæ, the difference being that, in the visceral or ventral laminæ, all three layers of the blastoderm are concerned.

The folding in of the splanchnopleure, lined by hypoblast, pinches off, as it were, a portion of the yelk-sac, enclosing it in the body-cavity. This forms the rudiment of the alimentary canal, which at this period ends blindly toward the head and tail, while in the centre it communicates freely with the cavity of the yelk-sac through the canal termed *vitelline* or *omphalo-mesenteric duct.*

The yelk-sac thus becomes divided into two portions which communicate through the vitelline duct, that portion within the body giving rise, as above stated, to the digestive canal, and that outside the body remaining for some time as the *umbilical vesicle* (Fig. 417, *ys*). The hypoblast forming the epithelium of the intestine is of course continuous with the lining membrane of the umbilical vesicle, while the visceral plate of the mesoblast is continuous with the outer layer of the umbilical vesicle.

All the above details will be clear on reference to the accompanying diagrams.

FŒTAL MEMBRANES.

Umbilical Vesicle or Yelk-sac.—The splanchnopleure, lined by hypoblast, forms the yelk-sac in Reptiles, Birds, and Mammals; but in Amphibia and Fishes, since there is neither *amnion* nor *allantois*, the wall of the yelk-sac consists of all three layers of the blastoderm, enclosed, of course, by the original vitelline membrane.

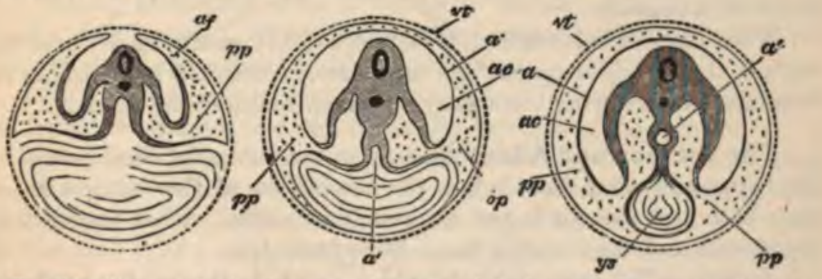


FIG. 417.—Diagrams, showing three successive stages of development. Transverse vertical sections. The yelk-sac, *ys*, is seen progressively diminishing in size. In the embryo itself the medullary canal and notochord are seen in section. *a'*, in middle figure, the alimentary canal, becoming pinched off, as it were, from the yelk-sac; *a'*, in right hand figure, alimentary canal completely closed; *a*, in last two figures, amnion; *ac*, cavity of amnion filled with amniotic fluid; *pp*, space between amnion and chorion, continuous with the pleuro-peritoneal cavity inside the body; *vt*, vitelline membrane; *ys*, yelk-sac, or umbilical vesicle. (Foster and Balfour.)

The body of the embryo becomes in great measure detached from the yelk-sac or umbilical vesicle, which contains, however, the greater part of the substance of the yelk, and furnishes a source whence nutriment is derived for the embryo. This nutriment is absorbed by the numerous vessels (omphalo-mesenteric) which ramify in the walls of the yelk-sac, forming what in birds is termed the *area vasculosa.* In Birds, the contents of the yelk-sac afford nourishment until the end of incubation, and the omphalo-mesenteric vessels are developed to a corresponding degree; but in Mammalia the office of the umbilical vesicle ceases at a very early period, the quantity of the yelk is small, and the embryo soon becomes independent of it by the connections it forms with the parent. Moreover, in Birds, as the sac is emptied, it is gradually drawn into the abdomen through the umbilical opening, which then closes over it: but in Mammalia it always remains on the outside; and as it is emptied it contracts (Fig. 419), shrivels up, and together with the part of its duct external to the abdomen, is detached and disappears either before or at the termination of intra-uterine life, the period of its disappearance varying in different orders of Mammalia.

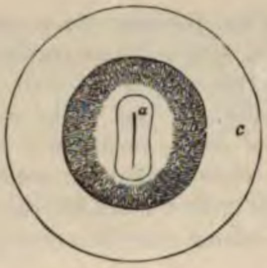


FIG. 418.

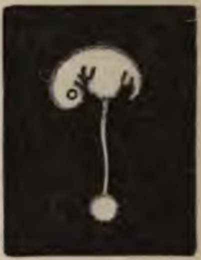


FIG. 419.

FIG. 418.—Diagram showing vascular area in the chick. *a*, area pellucida; *b*, area vasculosa; *c*, area vitellina.

FIG. 419.—Human embryo of fifth week with umbilical vesicle; about natural size (Dalton). The human umbilical vesicle never exceeds the size of a small pea.

When blood-vessels begin to be developed, they ramify largely over the walls of the umbilical vesicle, and are actively concerned in absorbing its contents and conveying them away for the nutrition of the embryo.

The Amnion and Allantois.—At an early stage of development of the fœtus, and some time before the completion of the changes which have been just described, two important structures, called respectively the *amnion* and the *allantois*, begin to be formed.

Amnion.—The amnion is produced as follows:—Beyond the head and tail-folds before described (p. 259, Vol. II.), the somatopleure coated by epiblast, is raised into folds, which grow up, arching over the embryo, not only anteriorly and posteriorly but also laterally, and all converging toward one point over its dorsal surface (Fig. 417). The growing up of these folds from all sides and their convergence toward one point very closely resembles the folding inward of the visceral plates already described, and hence, by some, the point at which the amniotic folds meet over the back has been termed the "amniotic umbilicus."

The folds not only come into contact but coalesce. The inner of the two layers forms the *true amnion*, while the outer or reflected layer, sometimes termed the *false amnion*, coalesces with the inner surface of the original vitelline membrane to form the *chorion*. This growth of the amniotic folds must of course be clearly distinguished from the very similar process, already described, by which the walls of the neural canal are formed at a much earlier stage.

Amniotic Cavity.—The cavity between the true amnion and the external surface of the embryo becomes a closed space, termed the *amniotic cavity* (*ac*, Fig. 417).

At first, the amnion closely invests the embryo, but it becomes gradually distended with fluid (liquor amnii), which, as pregnancy advances, reaches a considerable quantity.

This fluid consists of water containing small quantities of albumen and urea. Its chief function during gestation appears to be the mechanical one of affording equal support to the embryo on all sides, and of protecting it as far as possible from the effects of blows and other injuries to the abdomen of the mother.

The embryo up to the end of pregnancy is thus immersed in fluid, which during parturition serves the important purpose of gradually and evenly dilating the neck of the uterus to allow of the passage of the fœtus: when this is accomplished the amniotic sac bursts and the "waters" escape.

On referring to the diagrams (Fig. 417), it will be obvious that the cavity outside the amnion (between it and the false amnion) is continuous with the pleuro-peritoneal cavity at the umbilicus. This cavity is not entirely obliterated even at birth, and contains a small quantity of fluid ("false waters"), which is discharged during parturition either before, or at the same time, as the amniotic fluid.

Allantois.—Into the pleuro-peritoneal space the *allantois* sprouts out, its formation commencing during the development of the amnion.

Growing out from or near the hinder portion of the intestinal canal (*c*, Fig. 420), with which it communicates, the allantois is at first a solid pear-shaped mass of splanchnopleure; but becoming vesicular by the projection into it of a hollow outgrowth of hypoblast, and very soon simply membranous and vascular, it insinuates itself between the amniotic folds, just described, and comes into close contact and union with the outer of the two folds, which has itself, as before said, become one with the external investing membrane of the egg. As it grows, the allantois developes muscular tissue in its external wall and becomes exceedingly vascular; in birds (Fig. 421) it envelopes the whole embryo—taking up vessels, so to speak, to the outer investing membrane of the egg, and lining the inner surface of the shell with a vascular membrane, by these means affording an extensive surface in which the blood may be aërated. In the human subject and in other Mammalia, the vessels carried out by the allantois are distributed only to a special part of the outer membrane or *chorion*, where, by interlacement with the vascular system of the mother, a structure called the *placenta* is developed.

In Mammalia, as the visceral laminæ close in the abdominal cavity, the allantois is thereby divided at the umbilicus into two portions; the outer part, extending from the umbilicus to the *chorion*, soon shriveling; while the inner part, remaining in the abdomen, is in part converted into the urinary bladder; the portion of the inner part not so converted, extending from the bladder to the umbilicus, under the name of the *urachus*. After birth the umbilical cord, and with it the external and shriveled portion of the allantois, are cast off at the umbilicus, while the *urachus* remains as an impervious cord stretched from the top of the urinary bladder to the umbilicus, in the middle line of the body, immediately beneath the parietal layer of the peritoneum. It is sometimes enumerated among the ligaments of the bladder.

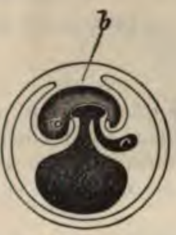


FIG. 420.

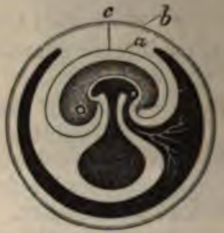


FIG. 421.

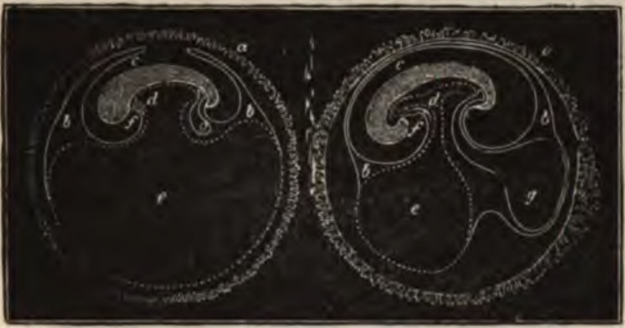
FIG. 420.—Diagram of fecundated egg. *a*, umbilical vesicle; *b*, amniotic cavity; *c*, allantois. (Dalton.)

FIG. 421.—Fecundated egg with allantois nearly complete. *a*, inner layer of amniotic fold; *b*, outer layer of ditto; *c*, point where the amniotic folds come in contact. The allantois is seen penetrating between the outer and inner layers of the amniotic folds. This figure, which represents only the amniotic folds and the parts within them, should be compared with Figs. 417, 423, in which will be found the structures external to these folds. (Dalton.)

It must not be supposed that the phenomena which have been successively described, occur in any regular order one after another. On the contrary, the development of one part is going on side by side with that of another.

The Chorion.—It has been already remarked that the *allantois* is a structure which extends from the body of the fœtus to the outer investing membrane of the ovum, that it insinuates itself between the two layers of the amniotic fold, and becomes fused with the outer layer, which has itself become previously fused with the vitelline membrane. By these means the external investing membrane of the ovum, or the *chorion*, as it is now called, represents three layers, namely, the original vitelline membrane, the outer layer of the amniotic fold, and the allantois.

Very soon after the entrance of the ovum into the uterus, in the human subject, the outer surface of the chorion is found beset with fine processes, the so-called *villi of the chorion* (Figs. 422, 423), which give it a rough and shaggy appearance. At first only cellular in structure, these little outgrowths subsequently become vascular by the development in them of loops of capillaries (Fig. 423); and the latter at length form the minute extremities of the blood-vessels which are, so to speak, conducted from the fœtus to the chorion by the allantois. The function of the villi of the chorion is evidently the absorption of nutrient matter for the fœtus; and this is probably supplied to them at first from the fluid matter, secreted by the follicular glands of the uterus, in which they are soaked. Soon, however, the fœtal vessels of the villi come into more intimate relation with the vessels of the uterus. The part at which this relation between the vessels of the fœtus and those of the parent ensues, is not, however, over the whole surface of the chorion: for, although all the villi become vascular, yet they become indistinct or disappear except at one part, where they are greatly developed, and by their branching give rise, with the vessels of the uterus, to the formation of the *placenta*.



FIGS. 422 and 423 (after Todd and Bowman). *a*, chorion with villi. The villi are shown to be best developed in the part of the chorion to which the allantois is extending; this portion ultimately becomes the placenta; *b*, space between the two layers of the amnion; *c*, amniotic cavity; *d*, situation of the intestine, showing its connection with the umbilical vesicle; *e*, umbilical vesicle; *f*, situation of the heart and vessels; *g*, allantois.

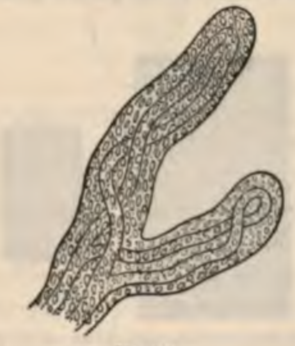


FIG. 424.

To understand the manner in which the *fœtal* and *maternal* blood-vessels come into relation with each other in the placenta, it is necessary briefly to notice the changes which the uterus undergoes after impregnation. These changes consist especially of alterations in structure of the superficial part of the mucous membrane which lines the interior of the uterus, and which forms, after a kind of development to be immediately described, the *membrana decidua*, so called on account of its being discharged from the uterus at birth.

FORMATION OF THE PLACENTA.

The mucous membrane of the human uterus, which consists of a matrix of connective tissue containing numerous corpuscles (adenoid tissue), and is lined internally by columnar ciliated epithelium, is abundantly beset with tubular glands, arranged perpendicularly to the surface (Fig. 425). These follicles are very small in the unimpregnated uterus; but when examined shortly after impregnation, they are found elongated, enlarged, and much waved and contorted toward their deep and closed extremity, which is implanted at some depth in the tissue of the uterus, and may dilate into two or three closed sacculi (Fig. 425).

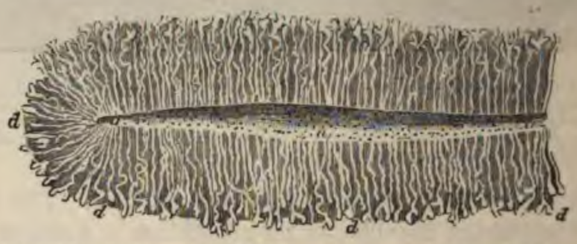


FIG. 425.—Section of the lining membrane of a human uterus at the period of commencing pregnancy, showing the arrangement and other peculiarities of the glands, *d*, *d*, *d*, with their orifices, *a*, *a*, *a*, on the internal surface of the organ. Twice the natural size.

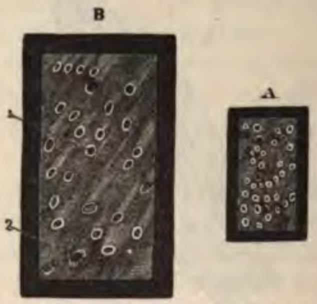


FIG. 426.—Two thin segments of human decidua after recent impregnation, viewed on a dark ground; they show the openings on the surface of the membrane. A is magnified six diameters, and B twelve diameters. At 1, the lining of epithelium is seen within the orifices, at 2 it has escaped. (Sharpey.)

The glands are lined by columnar ciliated epithelium, and they open on the inner surface of the mucous membrane by small round orifices set closely together (*a*, *a*, Fig. 426).

On the internal surface of the mucous membrane may be seen the circular orifices of the glands, many of which are, in the early period of pregnancy, surrounded by a whitish ring, formed of the epithelium which lines the follicles (Fig. 426).

Membrana decidua.—Coincidently with the occurrence of pregnancy, important changes occur in the structure of the mucous membrane of the uterus. The epithelium and sub-epithelial connective tissue, together with the tubular glands, increase rapidly, and there is a greatly increased vascularity of the whole mucous membrane, the vessels of the mucous membrane becoming larger and more numerous; while a substance composed chiefly of nucleated cells fills up the interfollicular spaces in which the blood-vessels are contained. The effect of these changes is an increased thickness, softness, and vascularity of the mucous membrane, the superficial part of which itself forms the *membrana decidua.*

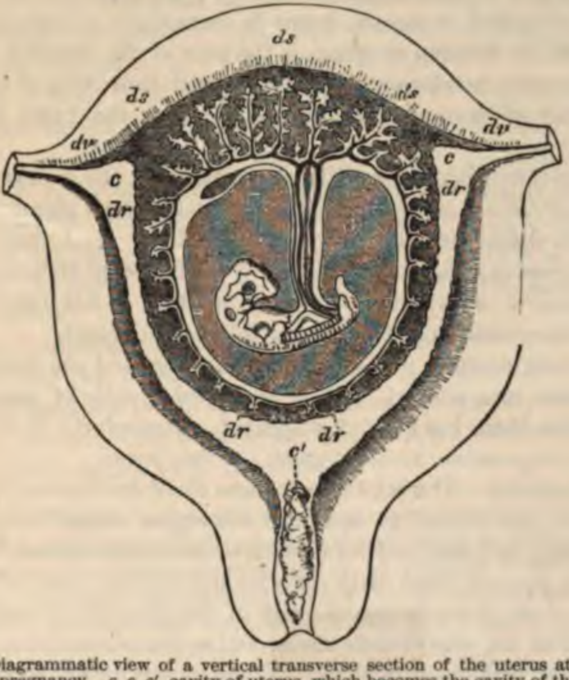


FIG. 427.—Diagrammatic view of a vertical transverse section of the uterus at the seventh or eighth week of pregnancy. *c*, *c*, *c'*, cavity of uterus, which becomes the cavity of the decidua, opening at *c*, *c*, the cornua, into the Fallopian tubes, and at *c'* into the cavity of the cervix, which is closed by a plug of mucus; *d v*, decidua vera; *d r*, decidua reflexa, with the sparser villi imbedded in its substance; *d s*, decidua serotina, involving the more developed chorionic villi of the commencing placenta. The fœtus is seen lying in the amniotic sac; passing up from the umbilicus is seen the umbilical cord and its vessels, passing to their distribution in the villi of the chorion; also the pedicle of the yelk-sac, which lies in the cavity between the amnion and chorion. (Allen Thomson.)

The object of this increased development seems to be the production of nutritive materials for the ovum; for the cavity of the uterus shortly becomes filled with secreted fluid, consisting almost entirely of nucleated cells in which the villi of the chorion are imbedded.

When the ovum first enters the uterus it becomes imbedded in the structure of the decidua, which is yet quite soft, and in which soon afterward three portions are distinguishable. These have been named the decidua *vera*, the decidua *reflexa*, and the decidua *serotina*. The first of these, the decidua *vera*, lines the cavity of the uterus; the second, or decidua *reflexa*, is a part of the decidua vera which grows up around the ovum, and, wrapping it closely, forms its immediate investment.

The third, or decidua *serotina*, is the part of the decidua vera which becomes especially developed in connection with those villi of the chorion which, instead of disappearing, remain to form the fœtal part of the *placenta*.

In connection with these villous *processes* of the chorion, there are developed *depressions* or *crypts* in the decidual mucous membrane, which correspond in shape with the villi they are to lodge; and thus the chorionic villi become more or less imbedded in the maternal structures. These uterine crypts, it is important to note, are not, as was once supposed, merely the open mouths of the uterine follicles (Turner).

As the ovum increases in size, the decidua vera and the decidua reflexa gradually come into contact, and in the third month of pregnancy the cavity between them has quite disappeared. Henceforth it is very difficult, or even impossible, to distinguish the two layers.

The Placenta.—During these changes the deeper part of the mucous membrane of the uterus, at and near the region where the placenta is placed, becomes hollowed out by sinuses, or cavernous spaces, which communicate on the one hand with arteries and on the other with veins of the uterus. Into these sinuses the villi of the chorion protrude, pushing the thin wall of the sinus before them, and so come into intimate relation with the blood contained in them. There is no direct communication between the blood-vessels of the mother and those of the fœtus; but the layer or layers of membrane intervening between the blood of the one and of the other offer no obstacle to a free interchange of matters between them. Thus the villi of the chorion containing fœtal blood, are bathed or soaked in maternal blood contained in the uterine sinuses. The arrangement may be roughly compared to filling a glove with fœtal blood, and dipping its fingers into a vessel containing maternal blood. But in the fœtal villi there is a constant stream of blood into and out of the loop of capillary blood-vessels contained in it, as there is also into and out of the maternal sinuses.

It would seem from the observations of Goodsir, that, at the villi of the placental tufts, where the fœtal and maternal portions of the placenta are brought into close relation with each other, the blood in the vessels of the mother is separated from that in the vessels of the fœtus by the intervention of two distinct sets of nucleated cells (Fig. 428). One of these (*b*) belongs to the maternal portion of the placenta, is placed between the membrane of the villus and that of the vascular system of the mother, and is probably designed to separate from the blood of the parent the materials destined for the blood of the fœtus; the other (*f*) belongs to the fœtal portion of the placenta, is situated between the membrane of the villus and the loop of vessels contained within, and probably serves for the absorption of the material secreted by the other sets of cells, and for its conveyance into the blood-vessels of the fœtus. Between the two sets of cells with their investing membrane there exists a space (*d*), into which it is probable that the materials secreted by the one set of cells of the villus are poured in order that they may be absorbed by the other set, and thus conveyed into the fœtal vessels.

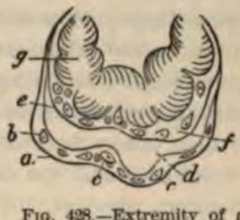


FIG. 428.—Extremity of a placental villus *a*, lining membrane of the vascular system of the mother; *b*, cells immediately lining *a*; *d*, space between the maternal and fœtal portions of the villus; *e*, internal membrane of the villus, or external membrane of the chorion; *f*, internal cells of the villus, or cells of the chorion; *g*, loop of umbilica vessels. (Goodsir.)

Not only, however, is there a passage of materials from the blood of the mother into that of the fœtus, but there is a mutual interchange of materials between the blood both of fœtus and of parent; the latter supplying the former with nutriment, and in turn abstracting from it materials which require to be removed.

Alexander Harvey's experiments were very decisive on this point. The view has also received abundant support from Hutchinson's important observations on the communication of syphilis from the father to the mother, through the instrumentality of the fœtus; and still more from Savory's experimental researches, which prove quite clearly that the female parent may be directly inoculated through the fœtus. Having opened the abdomen and uterus of a pregnant bitch, Savory injected a solution of strychnia into the abdominal cavity of one fœtus, and into the thoracic cavity of another, and then replaced all the parts, every precaution being taken to prevent escape of the poison. In less than half an hour the bitch died from tetanic spasms: the fœtuses operated on were also found dead, while the others were alive and active. The experiments, repeated on other animals with like results, leave no doubt of the rapid and direct transmission of matter from the fœtus to the mother, through the blood of the placenta.

The placenta, therefore, of the human subject is composed of a *fœtal* part and a *maternal* part,—the term placenta properly including all that entanglement of fœtal villi and maternal sinuses, by means of which the blood of the fœtus is enriched and purified after the fashion necessary for the proper growth and development of those parts which it is designed to nourish.

The importance of the placenta is at once apparent if we remember that, during the greater portion of intra-uterine life, the maternal blood circulating in its vessels supplies the fœtus with both food and oxygen. It thus performs the functions which in later life are discharged by the alimentary canal and lungs.

The whole of this structure is not, as might be imagined, thrown off immediately after birth. The greater part, indeed, comes away at that time, as the *after-birth;* and the separation of this portion takes place by a rending or crushing through of that part at which its cohesion is least strong, namely, where it is most burrowed and undermined by the cavernous spaces before referred to. In this way it is cast off with the fœtal membrane and the decidua *vera* and *reflexa,* together with a part of the decidua *serotina.* The remaining portion withers, and disappears by being gradually either absorbed, or thrown off in the uterine discharges or the *lochia,* which occur at this period.

A new mucous membrane is of course gradually developed, as the old one, by its peculiar transformation into what is called the decidua, ceases to perform its original functions.

The *umbilical cord,* which in the latter part of fœtal life is almost solely composed of the two arteries and the single vein which respectively convey fœtal blood to and from the placenta, contains the remnants of other structures which in the early stages of the development of the embryo were, as already related, of great comparative importance. Thus, in early fœtal life, it is composed of the following parts:—(1.) Externally, a layer of the amnion, reflected over it from the umbilicus. (2.) The umbilical vesicle with its duct and appertaining omphalo-mesenteric blood-vessels. (3.) The remains of the allantois, and continuous with it the urachus. (4.) The umbilical vessels, which, as just remarked, ultimately form the greater part of the cord.

DEVELOPMENT OF ORGANS.

It remains now to consider in succession the development of the several organs and systems of organs in the further progress of the embryo. The accompanying figure (Fig. 429) shows the chief organs of the body in a moderately early stage of development.

DEVELOPMENT OF THE VERTEBRAL COLUMN AND CRANIUM.

The primitive part of the vertebral column in all the Vertebrata is the *chorda dorsalis* (notochord), which consists entirely of soft cellular cartilage. This cord tapers to a point at the cranial and caudal extremities of the animal. In the progress of its development, it is found to become enclosed in a membranous sheath, which at length acquires a fibrous structure, composed of transverse annular fibres. The chorda dorsalis is to be regarded as the azygos axis of the spinal column, and, in particular, of the future bodies of the vertebræ, although it never itself passes into the state of hyaline cartilage or bone, but remains enclosed as in a case within the persistent parts of the vertebral column which are developed around it. It is permanent, however, only in a few animals: in the majority only traces of it persist in the adult animal.

In many Fish no true vertebræ are developed, and there is every gradation from the *amphioxus*, in which the notochord persists through life and there are no vertebral segments, through the lampreys in which there are a few scattered cartilaginous segments, and the sharks, in which many of the vertebræ are partly ossified, to the bony fishes, such as the cod and herring, in which the vertebral column consists of a number of distinct ossified vertebræ, with remnants of the notochord between them. In Amphibia, Reptiles, Birds, and Mammals, there are distinct vertebræ, which are formed as follows:—

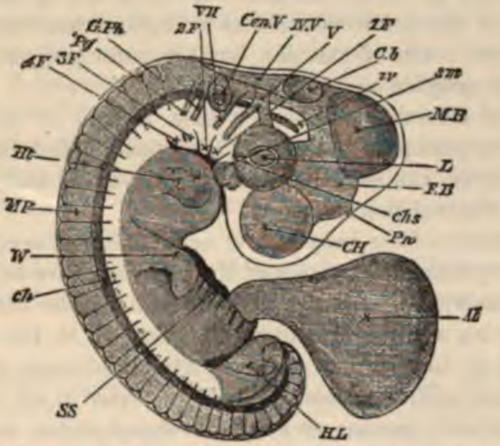


FIG. 429.—Embryo chick (4th day), viewed as a transparent object, lying on its left side (magnified). *C H*, cerebral hemispheres; *F B*, fore-brain or vesicle of third ventricle, with *P n*, pineal gland projecting from its summit; *M B*, mid-brain; *C b*, cerebellum; *IV V*, fourth ventricle; *L*, lens; *c h s*, choroidal slit; *Cen V*, auditory vesicle; *s m*, superior maxillary process; 1*F*, 2*F*, etc., first, second, third, and fourth visceral folds; *V*, fifth nerve, sending one branch (ophthalmic) to the eye, and another to the first visceral arch; *VII*, seventh nerve, passing to the second visceral arch; *G Ph*, glosso-pharyngeal nerve, passing to the third visceral arch; *P g*, pneumogastric nerve, passing toward the fourth visceral arch; *i v*, investing mass; *c h*, notochord; its front end cannot be seen in the living embryo, and it does not end as shown in the figure, but takes a sudden bend downward, and then terminates in a point; *H t*, heart seen through the walls of the chest; *M P*, muscle-plates; *W*, wing, showing commencing differentiation of segments, corresponding to arm, forearm, and hand; *H L*, hind-limb, as yet a shapeless bud, showing no differentiation. Beneath it is seen the curved tail. (Foster and Balfour.)

Protovertebræ.—The *protovertebræ*, which have been already mentioned (p. 258, Vol. II.), send processes downward and inward to surround the notochord, and also upward between the medullary canal and the epiblast covering it. In the former situation, the cartilaginous bodies of the vertebræ make their appearance, in the latter their arches, which enclose the neural canal.

The vertebræ do not exactly correspond in their position with the protovertebræ: but each permanent vertebra is developed from the contiguous halves of two protovertebræ. The original segmentation of the protovertebræ disappears and a fresh subdivision occurs in such a way that a permanent invertebral disc is developed opposite the centre of each protovertebra. Meanwhile the protovertebræ split into a dorsal and ventral portion. The former is termed the *musculo-cutaneous* plate, and from it are developed all the muscles of the back together with the cutis of the dorsal region (the epidermis being derived from the epiblast). The ventral portions of the protovertebræ, as we have already seen, give rise to the vertebræ and heads of the ribs, but the outer part of each also gives rise to a spinal ganglion and nerve-root.

The chorda is now enclosed in a case, formed by the bodies of the vertebræ, but it gradually wastes and disappears. Before the disappearance of the chorda, the ossification of the bodies and arches of the vertebræ begins at distinct points.

The ossification of the body of a vertebra is first observed at the point where the two primitive elements of the vertebræ have united inferiorly. Those vertebræ which do not bear ribs, such as the cervical vertebræ, have generally an additional centre of ossification in the transverse process, which is to be regarded as an abortive rudiment of a rib. In the fœtal bird, these additional ossified portions exist in all the cervical vertebræ, and gradually become so much developed in the lower part of the cervical region as to form the upper false ribs of this class of animals. The same parts exist in mammalia and man; those of the last cervical vertebræ are the most developed, and in children may, for a considerable period, be distinguished as a separate part on each side, like the root or head of a rib.

The true cranium is a prolongation of the vertebral column, and is developed at a much earlier period than the facial bones. Originally, it is formed of but one mass, a cerebral capsule, the chorda dorsalis being continued into its base, and ending there with a tapering point. At an early period the head is bent downward and forward round the end of the chorda dorsalis in such a way that the *middle* cerebral vesicle, and not the anterior, comes to occupy the highest position in the head.

Pituitary Body.—In connection with this must be mentioned the development of the pituitary body. It is formed by the meeting of two outgrowths, one from the fœtal brain, which grows downward, and the other from the epiblast of the buccal cavity, which grows up toward it. The surrounding mesoblast also takes part in its formation. The connection of the first process with the brain becomes narrowed, and persists as the infundibulum, while that of the other process with the buccal cavity disappears completely at a spot corresponding with the future position of the body of the sphenoid.

The first appearance of a solid support at the base of the cranium observed by Müller in fish, consists of two elongated bands of cartilage (trabeculæ cranii), one on the right and the other on the left side, which are connected with the cartilaginous capsule of the auditory apparatus, and which diverge to enclose the pituitary body, uniting in front to form the septum nasi beneath the anterior end of the cerebral capsule. Hence, in the cranium, as in the spinal column, there are at first developed at the sides of the chorda dorsalis two symmetrical elements, which subsequently coalesce, and may wholly enclose the chorda.

The brain-case consists of three segments: occipital, parietal, and frontal, corresponding in their relative position to the three primitive cerebral vesicles; it may also be noted that in front of each segment is developed a sense-organ (auditory, ocular, and olfactory, from behind forward). The basis cranii consists at an early period of an unsegmented cartilaginous rod, developed round the notochord, and continued forward beyond its termination into the *trabeculæ cranii,* which bound the pituitary fossa on either side.

In this cartilaginous rod three centres of ossification appear: basi-occipital, basi-sphenoid, and pre-sphenoid, one corresponding to each segment.

The bones forming the vault of the skull (frontal, parietal, squamous portion of temporal), with the exception of the squamo-occipital, which is pre-formed in cartilage, are ossified in membrane.

Development of the Face and Visceral Arches.

It has been said before that at an early period of development of the embryo, there grow up on the sides of the primitive groove the so-called *dorsal laminæ,* which at length coalesce, and complete by their union the spinal canal. The same process essentially takes place in the head, so as to enclose the cranial cavity.

Visceral Laminæ.—The so-called *visceral laminæ* have been also described as passing forward, and gradually coalescing in front, as the dorsal laminæ do behind, and thus enclosing the thoracic and abdominal cavity. An analogous process occurs in the facial and cervical regions, but the enclosing laminæ, instead of being simple, as in the former instances, are cleft.

In this way the so-called visceral *arches* and *clefts* are formed, four on each side (Fig. 430, A).

From or in connection with these arches the following parts are developed:—

The first arch (mandibular) contains a cartilaginous rod (Meckel's cartilage), around the distal end of which the lower jaw is developed, while the malleus is ossified from the proximal end.

From near the root of this arch the maxillary process grows forward and inward toward the middle line; from it are formed the superior maxillary and malar bones. A pair of cartilaginous rods (pterygo-palatine), parallel to the trabeculæ cranii, give origin to the external pterygoid plate of the sphenoid and the palate bones.

The cleft between the maxillary process and the mandibular (or first visceral arch) forms the mouth.

When the maxillary processes on the two sides fail partially or completely to unite in the middle line, the well-known condition termed *cleft palate* results. When the integument of the face presents a similar deficiency, we have the deformity known as *hare-lip*. Though these two deformities frequently co-exist, they are by no means always necessarily associated.

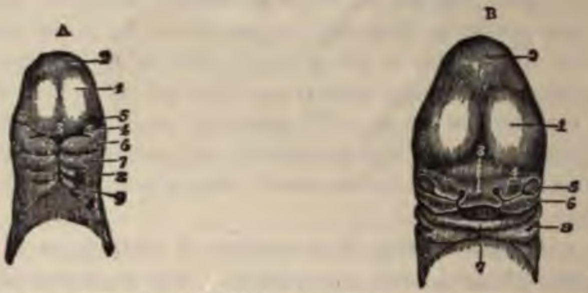


FIG. 430.—A. Magnified view from before of the head and neck of a human embryo of about three weeks (from Ecker). 1, anterior cerebral vesicle or cerebrum; 2, middle ditto; 3, middle or fronto-nasal process; 4, superior maxillary process; 5, eye; 6, inferior maxillary process, or first visceral arch, and below it the first cleft; 7, 8, 9, second, third, and fourth arches and clefts. B. Anterior view of the head of a human fœtus of about the fifth week (from Ecker, as before, Fig. IV.). 1, 2, 3, 5, the same parts as in A; 4, the external nasal or lateral frontal process; 6, the superior maxillary process; 7, the lower jaw; ×, the tongue; 8, first branchial cleft becoming the meatus auditorius externus.

The upper part of the face in the middle line is developed from the so-called *frontal-nasal* process (A, 3, Fig. 430). From the *second* arch are developed the *incus, stapes,* and *stapedius* muscle, the styloid process of the *temporal* bone, the *stylo-hyoid* ligament, and the *smaller cornu* of the *hyoid* bone. From the *third* visceral arch, the *greater cornu* and *body* of the hyoid bone. In man and other mammalia the *fourth* visceral arch is indistinct. It occupies the position where the neck is afterward developed.

A distinct connection is traceable between these visceral arches and certain cranial nerves: the trigeminal, the facial, the glosso-pharyngeal, and the pneumogastric. The ophthalmic division of the trigeminal supplies the trabecular arch; the superior and inferior maxillary divisions supply the maxillary and mandibular arches respectively.

The facial nerve distributes one branch (chorda tympani) to the first visceral arch, and others to the second visceral arch. Thus it divides, enclosing the first visceral cleft.

Similarly, the glosso-pharyngeal divides to enclose the second visceral cleft, its lingual branch being distributed to the second, and its pharyngeal branch to the third arch.

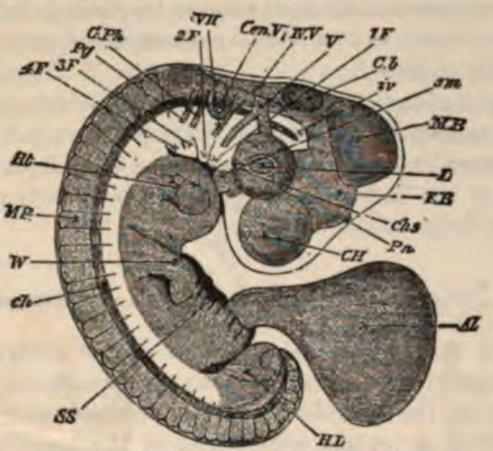


Fig. 431.—For description see Fig. 429.

The vagus, too, sends a branch (pharyngeal) along the third arch, and in fishes it gives off paired branches, which divide to enclose several successive branchial clefts.

Development of the Extremities.

The extremities are developed in a uniform manner in all vertebrate animals. They appear in the form of leaf-like elevations from the parietes of the trunk (see Fig. 432), at points where more or less of an arch will be produced for them within. The primitive form of the extremity

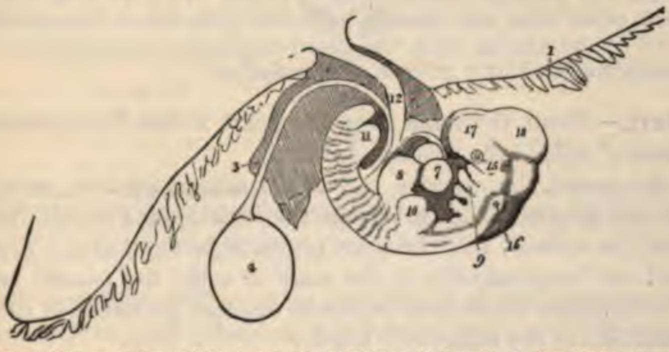


Fig. 432.—A human embryo of the fourth week; 3½ lines in length. 1, the chorion; 3, part of the amnion; 4, umbilical vesicle with its long pedicle passing into the abdomen; 7, the heart; 8, the liver; 9, the visceral arch destined to form the lower jaw, beneath which are two other visceral arches separated by the branchial clefts; 10, rudiment of the upper extremity; 11, that of the lower extremity; 12, the umbilical cord; 15, the eye; 16, the ear; 17, cerebral hemispheres; 18, optic lobes, corpora quadrigemina. (Müller.)

is nearly the same in all Vertebrata, whether it be destined for swimming, crawling, walking, or flying. In the human fœtus the fingers are at first united, as if webbed for swimming; but this is to be regarded not so much as an approximation to the form of aquatic animals, as the primitive form of the hand, the individual parts of which subsequently become more completely isolated.

The fore-limb always appears before the hind-limb and for some time continues in a more advanced state of development. In both limbs alike, the distal segment (hand or foot) is separated by a slight notch from the proximal part of the limb, and this part is subsequently divided again by a second notch (knee or elbow-joint).

DEVELOPMENT OF THE VASCULAR SYSTEM.

At an early stage in the development of the embryo-chick, the so-called "area vasculosa" begins to make its appearance. A number of branched cells in the mesoblast send out processes which unite so as to form a network of protoplasm with nuclei at the nodal points. A large number of the nuclei acquire a red color; these form the red blood-cells. The protoplasmic processes become hollowed out in the centre so as to form a closed system of branching canals, in the walls of which the rest of the nuclei remain imbedded. In the blood-vessels thus formed, the circulation of the embryonic blood commences.

According to Klein's researches, the first blood-vessels in the chick are developed from embryonic cells of the mesoblast, which swell up and become vacuolated, while their nuclei undergo segmentation. These cells send out protoplasmic processes, which unite with corresponding ones from other cells, and become hollowed, give rise to the capillary wall composed of endothelial cells; the blood-corpuscles being budded off from the endothelial wall by a process of gemmation.

Heart.—About the same time the heart makes its appearance as a solid mass of cells of the splanchnopleure.

At this period the anterior part of the alimentary tube ends blindly beneath the notochord. It is beneath the posterior end of this "fore-gut" (as it may be termed) that the heart begins to be developed. A cavity is hollowed out longitudinally in the mass of cells; the central cells float freely in the fluid, which soon begins to circulate by means of the rhythmic pulsations of the embryonic heart.

These pulsations take place even before the appearance of a cavity, and immediately after the first "laying down" of the cells from which the heart is formed, and long before muscular fibres or ganglia have been formed in the cardiac walls. At first they seldom exceed from fifteen to eighteen in the minute. The fluid within the cavity of the heart shortly assumes the characters of blood. At the same time the cavity itself forms a communication with the great vessels in contact with it, and the cells of which its walls are composed are transformed into fibrous and muscular tissues, and into epithelium. In the developing chick it can be observed with the naked eye as a minute red pulsating point before the end of the second day of incubation.

Blood-vessels.—Blood-vessels appear to be developed in two ways, according to the size of the vessels. In the formation of large blood-vessels, masses of embryonic cells similar to those from which the heart and other structures of the embryo are developed, arrange themselves in the position, form, and thickness of the developing vessel. Shortly afterward the cells in the interior of a column of this kind seem to be developed into blood-corpuscles, while the external layer of cells is converted into the walls of the vessel.

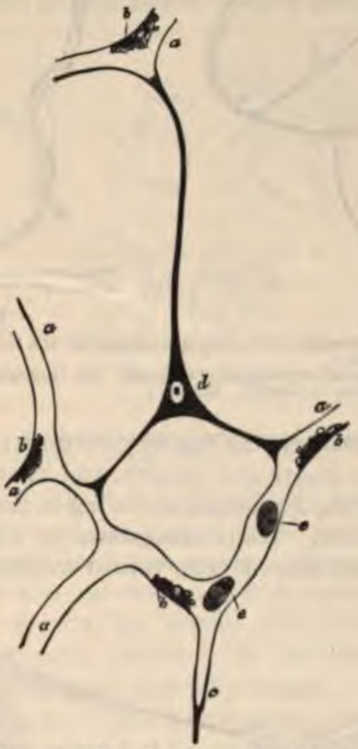


FIG. 433.—Capillary blood-vessels of the tail of a young larval frog. *a*, capillaries permeable to blood; *b*, fat-granules attached to the walls of the vessels, and concealing the nuclei; *c*, hollow prolongation of a capillary, ending in a point; *d*, a branching cell with nucleus and fat-granules; it communicates by three branches with prolongation of capillaries already formed; *e*, *e*, blood corpuscles still containing granules of fat. × 350 times. (Kölliker.)

Capillaries.—In the development of capillaries another plan is pursued. This has been well illustrated by Kölliker, as observed in the tails of tadpoles. The first lateral vessels of the tail have the form of simple arches, passing between the main artery and vein, and are produced by the junction of prolongations, sent from both the artery and vein, with certain elongated or star-shaped cells, in the substance of the tail. When these arches are formed and are permeable to blood, new prolongations pass from them, join other radiated cells, and thus form secondary arches (Fig. 434). In this manner, the capillary network extends in proportion as the tail increases in length and breadth, and it, at the same time, becomes more dense by the formation, according to the same plan, of fresh vessels within its meshes. The prolongations by which the vessels communicate with the star-shaped cells, consist at first of narrow pointed projections from the side of the vessels, which gradually elongate until they come in contact with the radiated processes of the cells. The thickness of such a prolongation often does not exceed that of a fibril of fibrous

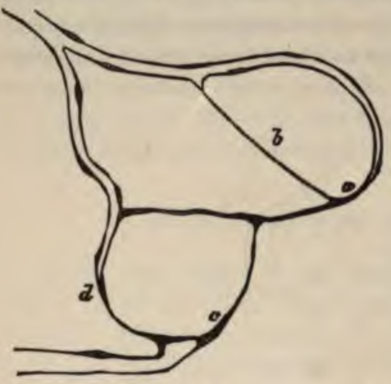


FIG. 434.

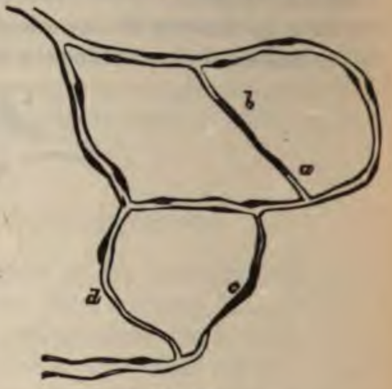


FIG. 435.

FIG. 434.—Development of capillaries in the regenerating tail of a tadpole. *a*, *b*, *c*, *d*, sprouts and cords of protoplasm. (Arnold.)

FIG. 435.—The same region after the lapse of 24 hours. The "sprouts and cords of protoplasm" have become channeled out into capillaries. (Arnold.)

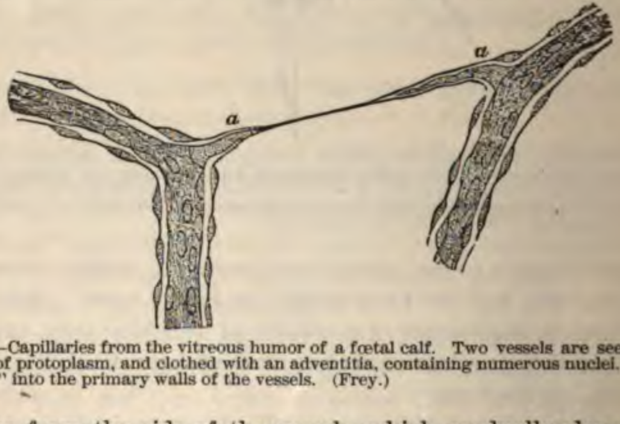


FIG. 436.—Capillaries from the vitreous humor of a fœtal calf. Two vessels are seen connected by a "cord" of protoplasm, and clothed with an adventitia, containing numerous nuclei. *a*, insertion of this "cord" into the primary walls of the vessels. (Frey.)

tissue, and at first it is perfectly solid; but, by degrees, especially after its junction with a cell, or with another prolongation, or with a vessel already permeable to blood, it enlarges, and a cavity then forms in its interior (see Figs. 434, 435). This tissue is well calculated to illustrate the various steps in the development of blood-vessels from elongating and branching cells.

In many cases a whole network of capillaries is developed from a network of branched, embryonic connective-tissue corpuscles bv the joining of their processes, the multiplication of their nuclei, and the vacuolation of the cell-substance. The vacuoles gradually coalesce till all the partitions are broken down and the originally solid protoplasmic cell-substance is, so to speak, tunneled out into a number of tubes.

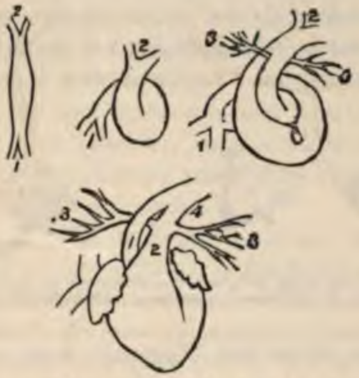


FIG. 437.—Fœtal heart in successive stages of development. 1, venous extremity; 2, arterial extremity; 3, 3, pulmonary branches; 4, ductus arteriosus. (Dalton.)

Capillaries may also be developed from cells which are originally spheroidal, vacuoles form in the interior of the cells, gradually becoming united by fine protoplasmic processes: by the extension of the vacuoles into them, capillary tubes are gradually formed.

Morphology. **Heart.**—When it first appears, the heart is approximately tubular in form. It receives at its two posterior angles the two omphalomesenteric veins, and gives off anteriorly the primitive aorta (Fig. 437).

It soon, however, becomes curved somewhat in the shape of a horseshoe, with the convexity toward the right, the venous end being at the same time drawn up toward the head, so that it finally lies behind and somewhat to the right of the arterial. It also becomes partly divided by constrictions into three cavities.

Of these three cavities which are developed in all Vertebrata, that at the venous end is the simple auricle, that at the arterial end the bulbus arteriosus, and the middle one is the simple ventricle.

These three parts of the heart contract in succession. The auricle and the bulbus arteriosus at this period lie at the extremities of the horseshoe.

The bulging out of the middle portion inferiorly gives the first indication of the future form of the ventricle (Fig. 438). The great curvature of the horseshoe by the same means becomes much more developed than the smaller curvature between the auricle and bulbus; and the two extremities, the auricle and bulb, approach each other superiorly, so as to produce a greater resemblance to the later form of the heart, whilst the ventricle becomes more and more developed inferiorly. The heart of Fishes retains these three cavities, no further division by internal septa into right and left chambers taking place. In Amphibia, also, the heart throughout life consists of the three muscular divisions which are so early formed in the embryo; but the auricle is divided internally by a septum into a pulmonary and systemic auricle. In Reptiles, not merely the auricle is thus divided into two cavities, but a similar septum is more or less developed in the ventricle. In Birds and Mammals, both auricle and ventricle undergo complete division by septa; whilst in these animals as well as in reptiles, the bulbus aortæ is not permanent, but becomes lost in the ventricles. The septum dividing the ventricle commences at the apex and extends upward. The subdivision of the auricles is very early foreshadowed by the outgrowth of the two auricular appendages, which occurs before any septum is formed externally. The septum of the auricles is developed from a semilunar fold, which extends from above downward. In man, the septum between the ventricles, according to Meckel, begins to be formed about the fourth week, and at the end of eight weeks is complete. The septum of the auricles, in man and all animals which possess it, remains imperfect throughout fœtal life. When the partition of the auricles is first commencing, the two venæ cavæ have different relations to the two cavities. The superior cava enters, as in the adult, into the right auricle; but the inferior cava is so placed that it appears to enter the left auricle, and the posterior part of the septum of the auricles is formed by the Eustachian valve, which extends from the point of entrance of the inferior cava. Subsequently, however, the septum, growing from the anterior wall close to the upper end of the ventricular septum, becomes directed more and more to the left of the vena cava inferior. During the entire period of fœtal life, there remains an opening in the septum, which the valve of the foramen ovale, developed in the third month, imperfectly closes.

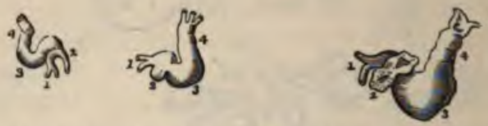


FIG. 438.—Heart of the chick at the 45th, 65th, and 85th hours of incubation. 1, the venous trunks; 2, the auricle; 3, the ventricle; 4, the bulbus arteriosus. (Allen Thomson.)

Bulbus Arteriosus.—The *bulbus arteriosus* which is originally a single tube, becomes gradually divided into two by the growth of an internal septum, which springs from the posterior wall, and extends forward toward the front wall and downward toward the ventricles. This partition takes a somewhat spiral direction, so that the two tubes (aorta and pulmonary artery) which result from its completion, do not run side by side, but are twisted round each other.

As the septum grows down toward the ventricles, it meets and coalesces with the upwardly growing ventricular septum, and thus from the right and left ventricles, which are now completely separate, arise respectively the pulmonary artery and aorta, which are also quite distinct. The auriculo-ventricular and semilunar valves are formed by the growth of folds of the endocardium.

At its first appearance the heart is placed just beneath the head of the fœtus, and is very large relatively to the whole body: but with the growth of the neck it becomes further and further removed from the head, and lodged in the cavity of the thorax.

Up to a certain period the auricular is larger than the ventricular division of the heart; but this relation is gradually reversed as development proceeds. Moreover, all through fœtal life, the walls of the right ventricle are of very much the same thickness as those of the left, which may probably be explained by the fact that in the fœtus the right ventricle has to propel the blood from the pulmonary artery into the aorta, and thence into the placenta, while in the adult it only drives the blood through the lungs.

Arteries.—The primitive aorta arises from the bulbus arteriosus and divides into two branches which arch backward, one on each side of the foregut, and unite again behind it, and in front of the notochord, into a single vessel.

This gives off the two omphalo-mesenteric arteries, which distribute branches all over the yolk-sac; this *area vasculosa* in the chick attaining a large development, and being limited all round by a vessel known as the sinus terminalis.

The blood is collected by the venous channels, and returned through the omphalo-mesenteric veins to the heart.

Behind this pair of primitive aortic arches, four more pairs make their appearance successively, so that there are five pairs in all, each one running along one of the visceral arches.

These five are never all to be seen at once in the embryo of higher animals, for the two anterior pairs gradually disappear, while the posterior ones are making their appearance, so that at length only three remain.

In Fishes, however, they all persist throughout life as the branchial arteries supplying the gills, while in Amphibia three pairs persist throughout life.

In Reptiles, Birds, and Mammals, further transformations occur.

In Reptiles the fourth pair remains throughout life as the permanent right and left aorta; in Birds the right one remains as the permanent aorta, curving over the right bronchus instead of the left as in Mammals.

In Mammals the left fourth aortic arch develops into the permanent aorta, the right one remaining as the subclavian artery of that side. Thus the subclavian artery on the right side corresponds to the aortic arch on the left, and this homology is further confirmed by the fact that the recurrent laryngeal nerve hooks under the subclavian on the right side, and the aortic arch on the left.

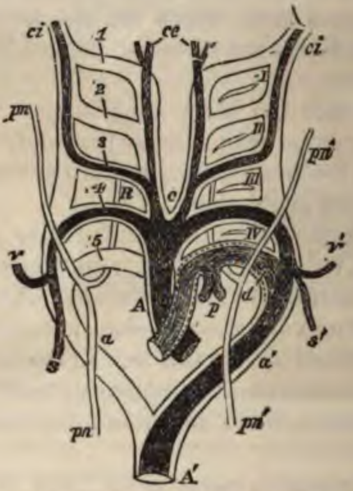
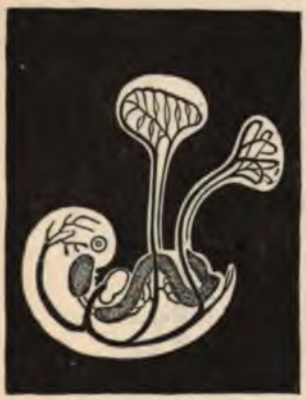


FIG. 439.—Diagram of the aortic arches in a mammal, showing transformations which give rise to the permanent arterial vessels. *A*, primitive arterial stem or aortic bulb, now divided into *A*, the ascending part of the aortic arch, and *p*, the pulmonary; *a a'*, right and left aortic roots; *A'*, descending aorta; 1, 2, 3, 4, 5, the five primitive aortic or branchial arches; *I*, *II*, *III*, *IV*, the four branchial clefts which, for the sake of clearness, have been omitted on the right side. The permanent systemic vessels are deeply, the pulmonary arteries, lightly shaded; the parts of the primitive arches which are transitory are simply outlined; *c*, placed between the permanent common carotid arteries; *c e*, external carotid arteries; *c i*, internal carotid arteries; *s*, right subclavian, rising from the right aortic root beyond the fifth arch; *v*, right vertebral from the same, opposite the fourth arch; *v' s'*, left vertebral and subclavian arteries rising together from the left, or permanent aortic root, opposite the fourth arch; *p*, pulmonary arteries rising together from the left fifth arch; *d*, outer or back part of left fifth arch, forming ductus arteriosus; *p n*, *p n*, right and left pneumogastric nerves, descending in front of aortic arches, with their recurrent branches represented diagrammatically as passing behind, to illustrate the relations of these nerves respectively to the right subclavian artery (4), and the arch of the aorta and ductus arteriosus (*d*). (Allen Thomson, after Rathke.)

The third aortic arch remains as the external carotid artery, while the fifth disappears on the right side, but on the left forms the pulmonary artery. The distal end of this arch originally opens into the descending aorta, and this communication (which is permanent throughout life in many reptiles on both sides of the body) remains throughout fœtal life under the name of *ductus arteriosus:* the branches of the pulmonary artery to the right and left lung are very small, and most of the blood which is forced into the pulmonary artery passes through the wide ductus arteriosus into the descending aorta. All these points will become clear on reference to the preceding diagram (Fig. 439).

As the umbilical vesicle dwindles in size, the portion of the omphalo-mesenteric arteries outside the body gradually disappears, the part inside the body remaining as the mesenteric arteries (Figs. 440, 441).

Meanwhile with the growth of the allantois two new arteries (umbilical) appear, and rapidly increase in size till they are the largest branches of the aorta: they are given off from the internal iliac arteries, and for a long time are considerably larger than the external iliacs which supply the comparatively small hind-limbs.



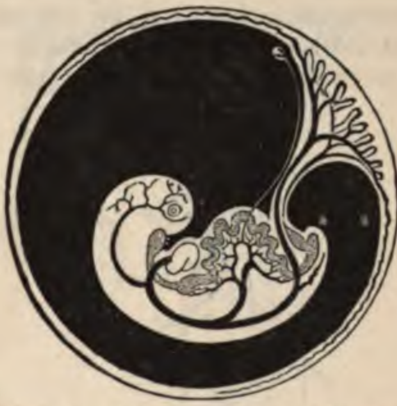


FIG. 440.—Diagram of young embryo and its vessels, showing course of circulation in the umbilical vesicle; and also that of the allantois (near the caudal extremity), which is just commencing. (Dalton.)

FIG. 441.—Diagram of embryo and its vessels at a later stage, showing the second circulation. The pharynx, œsophagus, and intestinal canal have become further developed, and the mesenteric arteries have enlarged, while the umbilical vesicle and its vascular branches are very much reduced in size. The large umbilical arteries are seen passing out in the placenta. (Dalton.)

Veins.—The chief veins in the early embryo may be divided into two groups, visceral and parietal: the former includes the omphalo-mesenteric and umbilical, the latter the jugular and cardinal veins. The former may be first considered.

The earliest veins to appear in the fœtus are the omphalo-mesenteric, which return the blood from the yolk-sac to the developing auricle. As soon as the placenta with its umbilical veins is developed, these unite with the omphalo-mesenteric, and thus the blood which reaches the auricle comes partly from the yolk-sac and partly from the placenta. The right omphalo-mesenteric and the right umbilical vein soon disappear, and the united left omphalo-mesenteric and umbilical veins pass through the developing liver on the way to the auricle. Two sets of vessels make their appearance in connection with the liver (venæ hepaticæ advehentes, and revehentes), both opening into the united omphalo-mesenteric and umbilical veins, in such a way that a portion of the venous blood traversing the latter is diverted into the developing liver, and, having passed through its capillaries, returns to the umbilical vein through the venæ hepaticæ revehentes at a point nearer the heart (see Fig. 442). The portion of vein between the afferent and efferent veins of the liver becomes the ductus venosus. The venæ hepaticæ advehentes become the right and left branches of the portal vein, the venæ hepaticæ revehentes become the hepatic veins, which open just at the junction of the ductus venosus with another large vein (vena cava inferior), which is now being developed. The mesenteric portion of the omphalo-mesenteric vein returning blood from the developing intestines remains as the mesenteric vein, which, by its union with the splenic vein, forms the portal.

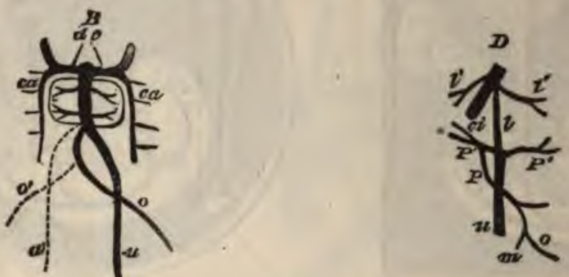


FIG. 442.—Diagrams illustrating the development of veins about the liver. *B*, *d c*, ducts of Cuvier, right and left; *c a*, right and left cardinal veins; *o*, left omphalo-mesenteric vein; *o'*, right omphalo-mesenteric vein, almost shriveled up; *u*, *u'*, umbilical veins, of which *u'*, the right one, has almost disappeared. Between the venæ cardinales is seen the outline of the rudimentary liver, with its venæ hepaticæ advehentes, and revehentes; *D*, ductus venosus; *l'*, hepatic veins; *c i*, vena cava inferior; *P*, portal vein; *P' P'*, venæ advehentes; *m*, mesenteric veins. (Kölliker.)

Thus the fœtal liver is supplied with venous blood from two sources, through the umbilical and portal vein respectively. At birth the circulation through the umbilical vein of course completely ceases and the vessel begins at once to dwindle, so that now the only venous supply of the liver is through the portal vein. The earliest appearance of the *parietal* system of veins is the formation of two short transverse veins (ducts of Cuvier) opening into the auricle on either side, which result from the union of a jugular vein, collecting blood from the head and neck, and a cardinal vein which returns the blood from the Wolffian bodies, the vertebral column, and the parietes of the trunk. This arrangement persists throughout life in Fishes, but in Mammals the following transformations occur.

As the kidneys are developing a new vein appears (vena cava inferior), formed by the junction of their efferent veins. It receives branches from the legs (iliac) and increases rapidly in size as they grow: further up it receives the hepatic veins. The heart gradually descends into the thorax, causing the ducts of Cuvier to become oblique instead of transverse. As the fore-limbs develop, the subclavian veins are formed.

A transverse communicating trunk now unites the two ducts of Cuvier, and gradually increases, while the left duct of Cuvier becomes almost entirely obliterated (all its blood passing by the communicating trunk to the right side) (Fig. 443, C, D). The right duct of Cuvier remains as the right innominate vein, while the communicating branch forms the left innominate. The remnant of the left duct of Cuvier generally remains as a fibrous band, running obliquely down to the coronary vein, which is really the proximal part of the left duct of Cuvier. In front of the root of the left lung, another relic may be found in the form of the so-called vestigial fold of Marshall, which is a fold of pericardium running in the same direction.

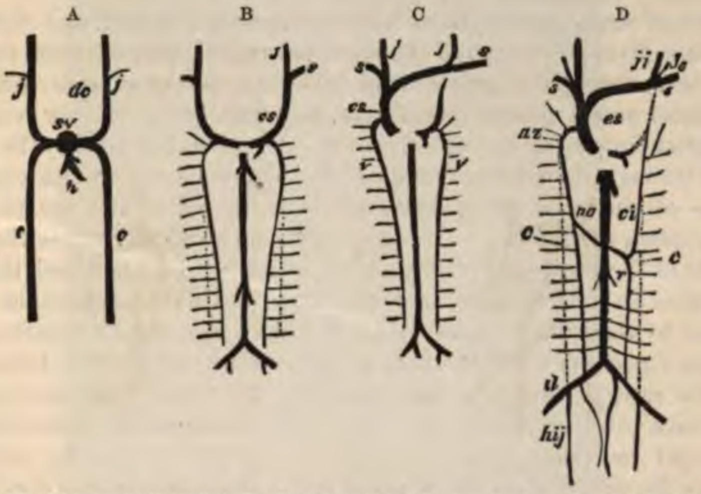


FIG. 443.—Diagrams illustrating the development of the great veins. *d c*, ducts of Cuvier; *j*, jugular veins; *h*, hepatic veins; *c*, cardinal veins; *s*, subclavian vein; *j i*, internal jugular vein; *j e*, external jugular vein; *a z*, azygos vein; *c i*, inferior vena cava; *r*, renal veins; *i l*, iliac veins; *h i j*, hypogastric veins. (Gegenbaur.)

In many of the lower mammals, such as the rat, the left ductus Cuvieri remains as a left superior cava.

Meanwhile, a transverse branch carries across most of the blood of the left cardinal vein into the right; and by this union the great azygos vein is formed.

The upper portions of the left cardinal vein remain as the left superior intercostal and vena azygos minor (Fig. 443, D).

CIRCULATION OF BLOOD IN THE FŒTUS.

The circulation of blood in the fœtus differs considerably from that of the adult. It will be well, perhaps, to begin its description by tracing the course of the blood, which, after being carried out to the placenta by the two umbilical *arteries*, has returned, cleansed and replenished, to the fœtus by the umbilical vein.

It is at first conveyed to the under surface of the liver, and there the stream is divided,—a part of the blood passing straight on to the *inferior* vena cava, through a venous canal called the *ductus venosus*, while the remainder passes into the portal vein, and reaches the inferior vena cava only after circulating through the liver. Whether, however, by the direct route through the ductus venosus or by the roundabout way through the liver,—all the blood which is returned from the placenta by the umbilical vein reaches the inferior vena cava at last, and is carried by it to the right auricle of the heart, into which cavity is also pouring the blood that has circulated in the head and neck and arms, and has been brought to the auricle by the *superior* vena cava. It might be naturally expected that the two streams of blood would be mingled in the right auricle, but such is not the case, or only to a slight extent. The blood from the *superior* vena cava—the less pure fluid of the two—passes almost exclusively into the *right* ventricle, through the auriculo-ventricular opening, just as it does in the adult; while the blood of the *inferior* vena cava is directed by a fold of the lining membrane of the heart, called the *Eustachian valve*, through the foramen ovale into the *left* auricle, whence it passes into the *left* ventricle, and out of this into the aorta, and thence to all the body. The blood of the *superior* vena cava, which, as before said, passes into the right ventricle, is sent out thence in small amount through the pulmonary artery to the lungs, and thence to the *left* auricle, as in the adult. The greater part, however, by far, does not go to the lungs, but instead, passes through a canal, the *ductus arteriosus*, leading from the pulmonary artery into the aorta just below the origin of the three great vessels which supply the upper parts of the body; and there meeting that part of the blood of the inferior vena cava which has not gone into these large vessels, it is distributed with it to the trunk and lower parts,—a portion passing out by way of the two umbilical *arteries* to the placenta. From the placenta it is returned by the umbilical *vein* to the under surface of the liver, from which the description started.

Changes after Birth.—After birth the foramen ovale closes, and so do the ductus arteriosus and ductus venosus, as well as the umbilical vessels; so that the two streams of blood which arrive at the right auricle by the superior and inferior vena cava respectively, thenceforth mingle in this cavity of the heart, and passing into the right ventricle, go by way of the pulmonary artery to the lungs, and through these, after purification, to the left auricle and ventricle, to be distributed over the body. (See Chapter on Circulation.)

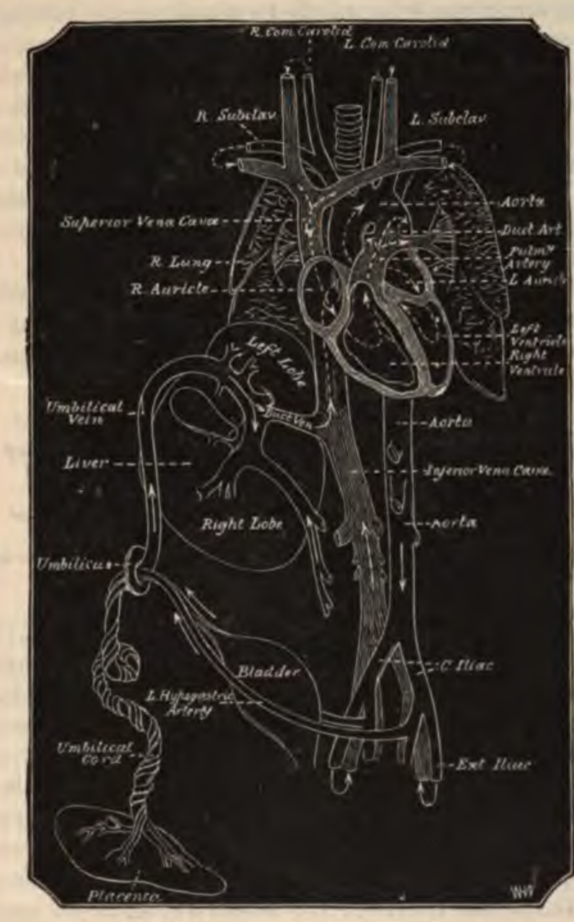


Fig. 444.—Diagram of the Fœtal Circulation.

DEVELOPMENT OF THE NERVOUS SYSTEM.

Nerves.—All the spinal nerves are derived from the mesoblast; also all the cranial nerves, except the optic and olfactory, which are outgrowths of the anterior cerebral vesicles. From the same middle layer of the embryo are also derived the ganglia connected with these nerves, and the whole sympathetic system of nerves and ganglia.

Spinal Cord.—Both the brain and spinal cord have a different origin from that of the nerves which arise from them. These nerve-centres are developed entirely from the epiblast (possibly, however, a portion of the spinal cord originates in the mesoblast); while the nerves, as we have seen, are formed from mesoblast. The spinal cord is developed out of the primitive medullary tube which results from the folding in of the dorsal laminæ (*m*, Fig. 411).

Soon after it has closed in, this tube is found to be somewhat oval in section, with a central canal, which, in sections, presents the appearance of an elongated slit, slightly expanded at each end. The two opposite sides unite (Fig. 445) in the centre of the slit, dividing it into an anterior portion (the permanent central canal of the cord) and a posterior, which makes its way to the free surface, and persists as the posterior fissure of the cord, lodging a very fine process of pia mater.

At this period the cord consists almost entirely of grey matter, but the white matter, which is derived probably from the surrounding mesoblast, becomes deposited around it on all sides, growing up especially on the

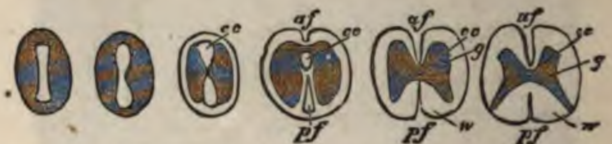


FIG. 445.—Diagram of development of spinal cord; *cc*, central canal; *af*, anterior fissure; *pf*, posterior fissure; *g*, grey matter; *w*, white matter. *For further explanation see text.*

anterior surface of the cord into the two anterior columns. These are separated by a fissure (anterior fissure of cord), which of course deepens as the columns bounding it become more prominent (Fig. 445).

By the development of various commissures. the cord is completed.

When it first appears, the spinal cord occupies the whole length of the medullary canal, but as development proceeds, the spinal column grows more rapidly than the contained cord, so that the latter appears as if drawn up till, at birth, it is opposite the third lumbar vertebra, and in the adult opposite the first lumbar. In the same way the increasing obliquity of the spinal nerves in the neural canal, as we approach the lumbar region, and the "cauda equina" at the lower end of the cord, are accounted for.

Brain.—We have seen (p. 257, Vol. II.) that the front portion of the medullary canal is almost from the first widened out and divided into three vesicles. From the anterior vesicle (thalamencephalon) the two primary optic vesicles are budded off laterally: their further history will be traced in the next section. Somewhat later, from the same vesicle the rudiments of the hemispheres appear in the form of two outgrowths at a higher level, which grow upward and backward. These form the *prosencephalon.*

In the walls of the posterior (third) cerebral vesicle, a thickening appears (rudimentary cerebellum) which becomes separated from the rest of the vesicle by a deep inflection.

At this time there are two chief curvatures of the brain (Fig. 446, 3). (1.) A sharp bend of the whole cerebral mass downward round the end of the notochord, by which the anterior vesicle, which was the highest of the three, is bent downward, and the middle one comes to occupy the highest position. (2.) A sharp bend, with the convexity forward, which runs in from behind beneath the rudimentary cerebellum separating it from the medulla.

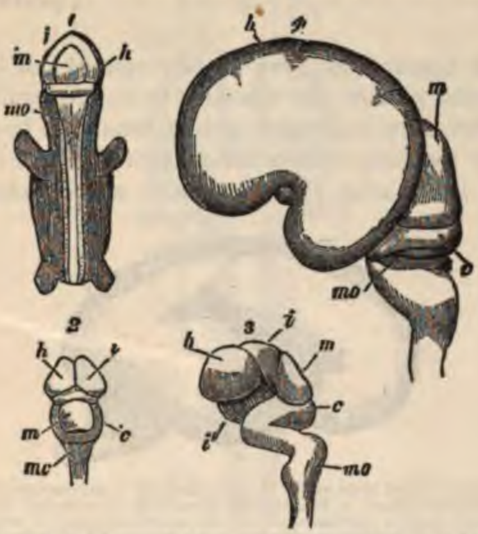


FIG. 446.—Early stages in development of human brain (magnified). 1, 2, 3, are from an embryo about seven weeks old; 4, about three months old. *m*, middle cerebral vesicle (mesencephalon); *c*, cerebellum; *m o*, medulla oblongata; *i*, thalamencephalon; *h*, hemispheres; *i'*, infundibulum. Fig. 3 shows the several curves which occur in the course of development. Fig. 4 is a lateral view, showing the great enlargement of the cerebral hemispheres which have covered in the thalami, leaving the optic lobes, *m*, uncovered. (Kölliker.)

N.B.—In Fig. 2 the line *i* terminates in the right hemisphere; it ought to be continued into the thalamencephalon.

Thus, five fundamental parts of the fœtal brain may be distinguished, which, together with the parts developed from them may be presented in the following tabular view.

Table of Parts Developed from Fundamental Parts of Brain.

I. Anterior Primary Vesicle.	1. Prosencephalon.	Cerebral hemispheres, corpora striata, corpus callosum, fornix, lateral ventricles, olfactory bulb (Rhinencephalon).
	2. Thalamencephalon (Diencephalon.)	Thalami optici, pineal gland, pituitary body, third ventricle, optic nerve (primarily).

II. Middle Primary Vesicle.	3. Mesencephalon.	Corpora quadrigemina, crura cerebri, aqueduct of Sylvius, optic nerve (secondarily).
III. Posterior Primary Vesicle.	4. Epencephalon.	Cerebellum, pons Varolii, anterior part of fourth ventricle.
	5. Metencephalon.	Medulla oblongata, fourth ventricle, auditory nerve.

(*Quain's Anatomy.*)

The cerebral hemispheres grow rapidly upward and backward, while from their inferior surface the olfactory bulbs are budded off, and the thalamencephalon, from which they spring, remains to form the third ventricle and optic thalami. The middle cerebral vesicle (mesencephalon) for some time is the most prominent part of the fœtal brain, and in Fishes, Amphibia, and Reptiles, it remains uncovered through life as the optic lobes. But in Birds the growth of the cerebral hemispheres thrusts the optic lobes down laterally, and in Mammalia completely overlaps them.

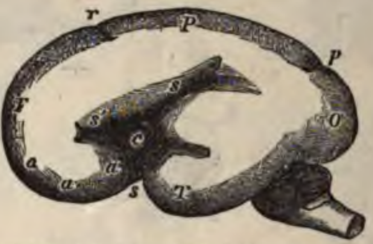


FIG. 447.—Side view of fœtal brain at six months, showing commencement of formation of the principal fissures and convolutions. *F*, frontal lobe; *P*, parietal; *O*, occipital; *T*, temporal; *a a a*, commencing frontal convolutions; *s*, Sylvian fissure; *s'*, its anterior division; *c*, within it the central lobe or island of Reil; *r*, fissure of Rolando; *p*, perpendicular fissure. (R. Wagner.)

In the lower Mammalia the backward growth of the hemispheres ceases as it were, but in the higher groups, such as the monkeys and man, they grow still further back, until they completely cover in the cerebellum, so that on looking down on the brain from above, the cerebellum is quite concealed from view. The surface of the hemispheres is at first quite smooth, but as early as the third mouth the great Sylvian fissure begins to be formed (Fig. 446, 4).

The next to appear is the parieto-occipital or perpendicular fissure; these two great fissures, unlike the rest of the sulci, are formed by a curving round of the whole cerebral mass.

In the sixth month the fissure of Rolando appears: from this time till the end of fœtal life the brain grows rapidly in size, and the convolutions appear in quick succession; first the great primary ones are sketched out, then the secondary, and lastly the tertiary ones in the sides of the fissures. The commissures of the brain (anterior, middle, and posterior), and the corpus callosum, are developed by the growth of fibres across the middle line.

The Hippocampus major is formed by the folding in of the grey matter from the exterior into the latter ventricles. The essential points in the structure and arrangement of the various parts of the brain, are diagrammatically shown in the two accompanying figures (Figs. 448, 449).

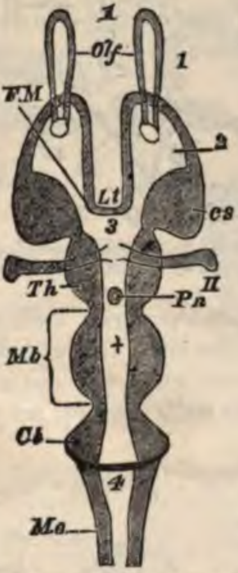


FIG. 448.—Diagrammatic horizontal section of a Vertebrate brain. The figures serve both for this and the next diagram. *Mb*, mid-brain: what lies in front of this is the fore, and what lies behind, the hind brain; *Lt*, lamina terminalis; *Olf*, olfactory lobes; *Hmp*, hemispheres; *TH.E*, thalamencephalon; *Pn*, pineal gland; *Py*, pituitary body; *FM*, foramen of Munro; *cs*, corpus striatum; *Th*, optic thalamus; *CC*, crura cerebri: the mass lying above the canal represents the corpora quadrigemina; *Cb*, cerebellum; *I—IX*, the nine pairs of cranial nerves; 1, olfactory ventricle; 2, lateral ventricle; 3, third ventricle; 4, fourth ventricle; +, iter a tertio ad quartum ventriculum. (Huxley.)

DEVELOPMENT OF THE ORGANS OF SENSE.

Eye.—Soon after the first three cerebral vesicles have become distinct from each other, the anterior one sends out a lateral vesicle from each side (primary optic vesicle), which grows out toward the free surface, its cavity of course communicating with that of the cerebral vesicle through the canal in its pedicle. It is soon met and invaginated by an in-growing process from the epiblast (Fig. 450), very much as the growing tooth is met by the process of epithelium which produces the enamel organ. This process of the epiblast is at first a depression which ultimately bcomes closed in at the edges so as to produce a hollow ball, which is thus completely severed from the epithelium with which it was originally continuous. From this hollow ball the crystalline lens is developed.

By the ingrowth of the lens the anterior wall of the primary optic vesicle is forced back nearly into contact with the posterior, and thus the primary optic vesicle is almost obliterated. The cells in the anterior wall are much longer than those of the posterior wall; from the former the retina proper is developed, from the latter the retinal pigment.

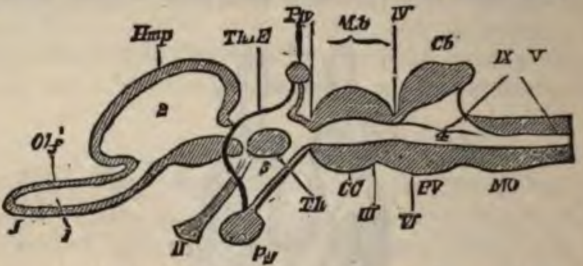


FIG. 449.—Longitudinal and vertical diagrammatic section of a *Vertebrate brain*. Letters as before. Lamina terminalis is represented by the strong black line joining *Pn* and *Py*. (Huxley.)

The cup-shaped hollow in which the lens is now lodged is termed the secondary optic vesicle: its walls grow up all round, leaving, however, a slit at the lower part.

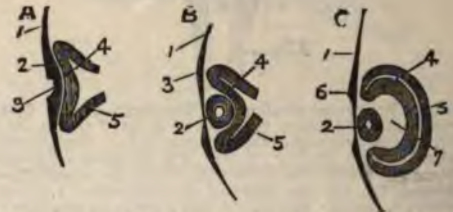


FIG. 450.—Longitudinal section of the primary optic vesicle in the chick magnified (from Remak). —A, from an embryo of sixty-five hours; B, a few hours later; C, of the fourth day; c, the corneous layer or epidermis, presenting in A, the open depression for the lens, which is closed in B and C; *l*, the lens follicle and lens; *pr*, the primary optic vesicle; in A and B, the pedicle is shown; in C, the section being to the side of the pedicle, the latter is not shown; *v*, the secondary ocular vesicle and vitreous humor.

Choroidal Fissure.—Through this slit (Fig. 452), often termed the *choroidal fissure*, a process of mesoblast containing numerous blood-vessels projects, and occupies the cavity of the secondary optic vesicle behind the lens, filling it with vitreous humor and furnishing the lens capsule and the capsulo-pupillary membrane. This process in Mammals projects, not only into the secondary optic vesicle, but also into the pedicle of the primary optic vesicle invaginating it for some distance from beneath, and thus carrying up the *arteria centralis retinæ* into its permanent position in the centre of the optic nerve.

This invagination of the optic nerve does not occur in *birds*, and consequently no arteria centralis retinæ exists in them. But they possess an important permanent relic of the original protrusion of the mesoblast through the choroidal fissure, forming the *pecten*, while a remnant of the same fissure sometimes occurs in man under the name coloboma iridis. The cavity of the primary optic vesicle becomes completely obliterated, and the rods and cones come into apposition with the pigment layer of the retina. The cavity of its pedicle disappears and the solid optic nerve is formed. Meanwhile the cavity which existed in the centre of the primitive lens becomes filled up by the growth of fibres from its posterior wall. The epithelium of the cornea is developed from the epiblast, while the corneal tissue proper is derived from the mesoblast which intervenes between the epiblast and the primitive lens which was originally continuous with it. The sclerotic coat is developed round the eyeball from the general mesoblast in which it is imbedded.

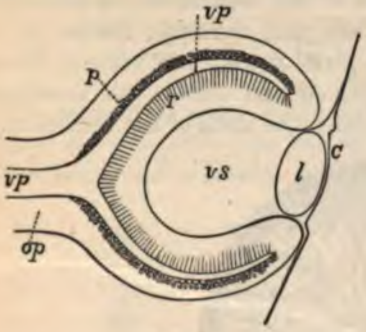


FIG. 451.

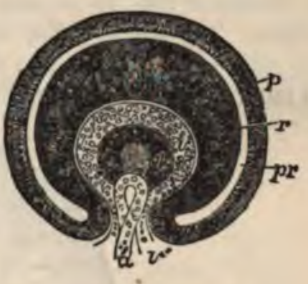


FIG. 452.

FIG. 451.—Diagrammatic sketch of a vertical longitudinal section through the eyeball of a human fœtus of four weeks. The section is a little to the side, so as to avoid passing through the ocular cleft; *c*, the cuticle where it becomes later the corneal epithelium; *l*, the lens; *op*, optic nerve formed by the pedicle of the primary optic vesicle; *vp*, primary medullary cavity or optic vesicle; *p*, the pigment layer of the retina; *r*, the inner wall forming the retina proper; *vs*, secondary optic vesicle containing the rudiment of the vitreous humor. × 100. (Kölliker.)

FIG. 452.—Transverse vertical section of the eyeball of a human embryo of four weeks. The anterior half of the section is represented; *pr*, the remains of the cavity of the primary optic vesicle; *p*, the inner part of the outer layer forming the retinal pigment; *r*, the thickened inner part giving rise to the columnar and other structures of the retina; *v*, the commencing vitreous humor within the secondary optic vesicle; *v'*, the ocular cleft through which the loop of the central blood-vessel, *a*, projects from below; *l*, the lens with a central cavity. × 100. (Kölliker.)

The iris is formed rather late, as a circular septum projecting inward, from the fore part of the choroid, between the lens and the cornea. In the eye of the fœtus of Mammalia, the pupil is closed by a delicate membrane, the *membrana pupillaris*, which forms the front portion of a highly vascular membrane that, in the fœtus, surrounds the lens, and is named the *membrana capsulo-pupillaris* (Fig. 453). It is supplied with blood by a branch of the *arteria centralis retinæ*, which, passing forward to the back of the lens, there subdivides. The membrana capsulo-pupillaris withers and disappears in the human subject a short time before birth.

The eyelids of the human subject and mammiferous animals, like those of birds, are first developed in the form of a ring. They then extend over the globe of the eye until they meet and become firmly agglutinated to each other. But before birth, or in the Carnivora after birth, they again separate.

Ear.—Very early in the development of the embryo a depression or ingrowth of the epiblast occurs on each side of the head which deepens and soon becomes a closed follicle. This *primary otic vesicle,* which closely corresponds in its formation to the lens follicle in the eye, sinks down to some distance from the free surface; from it are developed the epithelial lining of the *membranous* labyrinth of the internal ear, consisting of the vestibule and its semicircular canals and the scala media of the cochlea. The surrounding mesoblast gives rise to the various fibrous bony and cartilaginous parts which complete and enclose this membranous labyrinth, the bony semicircular canals, the walls of the cochlea with its scala vestibuli and scala tympani. In the mesoblast, between the primary otic vesicle and the brain, the auditory nerve is gradually differentiated and forms its central and peripheral attachments to the brain and internal ear respectively. According to some authorities, however, it is said to take its origin from and grow out of the hind brain.

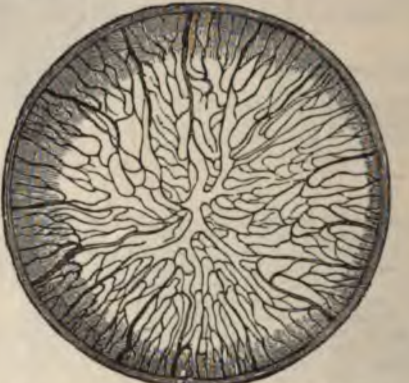


FIG. 453.—Blood-vessels of the capsulo-pupillary membrane of a new-born kitten, magnified. The drawing is taken from a preparation injected by Tiersch, and shows in the central part the convergence of the network of vessels in the pupillary membrane. (Kölliker.)

The Eustachian tube, the cavity of the tympanum, and the external auditory passage, are remains of the first branchial cleft. The membrana tympani divides the cavity of this cleft into an internal space, the tympanum and the external meatus. The mucous membrane of the mouth, which is prolonged in the form of a diverticulum through the Eustachian tube into the tympanum, and the external cutaneous system, come into relation with each other at this point; the two membranes being separated only by the proper membrane of the tympanum.

The pinna or external ear is developed from a process of integument in the neighborhood of the first and second visceral arches, and probably corresponds to the gill-cover (operculum) in fishes.

Nose.—The nose originates like the eye and ear in a depression of the superficial epiblast at each side of the fronto-nasal process (primary olfactory groove), which is at first completely separated from the cavity of the mouth, and gradually extends backward and downward till it opens into the mouth.

The outer angles of the fronto-nasal process, uniting with the maxillary process on each side, convert what was at first a groove into a closed canal.

DEVELOPMENT OF THE ALIMENTARY CANAL.

The alimentary canal in the earliest stages of its development consists of three distinct parts—the fore and hind gut ending blindly at each end of the body, and a middle segment which communicates freely on its ventral surface with the cavity of the yelk-sac through the vitelline or omphalo-mesenteric duct (p. 261, Vol. II.).

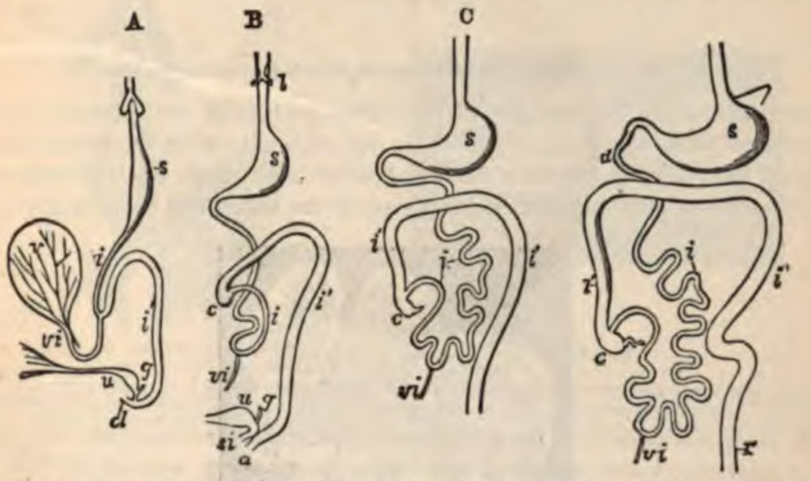


FIG. 454.—Outlines of the form and position of the alimentary canal in successive stages of its development. A, alimentary canal, etc., in an embryo of four weeks; B, at six weeks; C, at eight weeks; D, at ten weeks; *l*, the primitive lungs connected with the pharynx; *s*, the stomach; *d*, the duodenum; *i*, the small intestine; *i'*, the large; *c*, the cæcum and vermiform appendage; *r*, the rectum; *cl*, in A, the cloaca; *a*, in B, the anus distinct from *s i*, the sinus uro-genitalis; *v*, the yelk-sac; *v i*, the vitello-intestinal duct; *u*, the urinary bladder and urachus leading to the allantois; *g*, genital ducts. (Allen Thomson.)

From the fore-gut are formed the pharynx, œsophagus, and stomach; from the hind-gut, the lower end of the colon and the rectum. The mouth is developed by an involution of the epiblast between the maxillary and mandibular processes, which becomes deeper and deeper till it reaches the blind end of the fore-gut, and at length communicates freely with the pharynx by the absorption of the partition between the two.

At the other end of the alimentary canal the anus is formed in a precisely similar way by an involution from the free surface, which at length opens into the hind-gut. When the depression from the free surface does not reach the intestine, the condition known as imperforate anus results. A similar condition may exist at the other end of the alimentary canal from the failure of the involution which forms the mouth, to meet the fore-gut. The middle portion of the digestive canal becomes more and more closed in till its originally wide communication with the yelk-sac becomes narrowed down to a small duct (vitelline). This duct usually completely disappears in the adult, but occasionally the proximal portion remains as a diverticulum from the intestine. Sometimes a fibrous cord attaching some part of the intestine to the umbilicus, remains to represent the vitelline duct. Such a cord has been known to cause in after-life strangulation of the bowel and death.

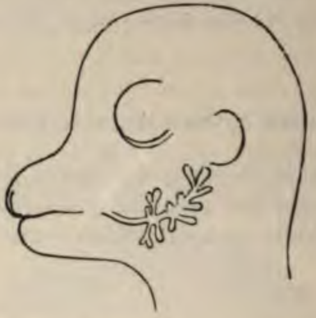


FIG. 455.—First appearance of the parotid gland in the embryo of a sheep.

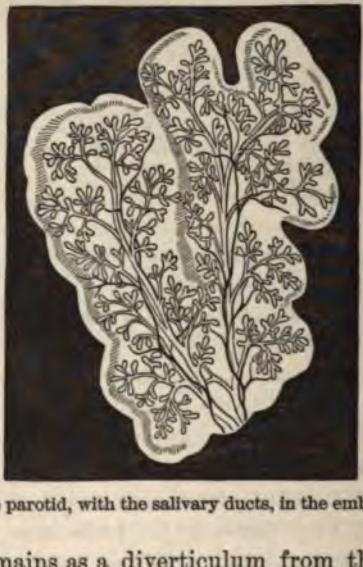


FIG. 456.—Lobules of the parotid, with the salivary ducts, in the embryo of the sheep at a more advanced stage.

The alimentary canal lies in the form of a straight tube close beneath the vertebral column, but it gradually becomes divided into its special parts, stomach, small intestine, and large intestine (Fig. 454), and at the same time comes to be suspended in the abdominal cavity by means of a lengthening mesentery formed from the splanchnopleure which attaches it to the vertebral column. The stomach originally has the same direction as the rest of the canal; its cardiac extremity being superior, its pylorus inferior. The changes of position which the alimentary canal undergoes may be readily gathered from the accompanying figures (Fig. 454).

Pancreas and Salivary Glands.—The principal glands in connection with the intestinal canal are the salivary, pancreas, and the liver. In Mammalia, each salivary gland first appears as a simple canal with bud-like processes (Fig. 455), lying in a gelatinous nidus or blastema, and communicating with the cavity of the mouth. As the development of the gland advances, the canal becomes more and more ramified, increasing at the expense of the blastema in which it is still enclosed. The branches or salivary ducts constitute an independent system of closed tubes (Fig. 456). The pancreas is developed exactly as the salivary glands, but is developed from the hypoblast lining the intestine, while the salivary glands are formed from the epiblast lining the mouth.

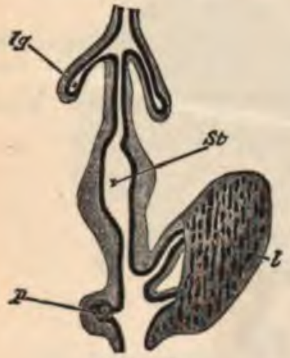


FIG. 457.

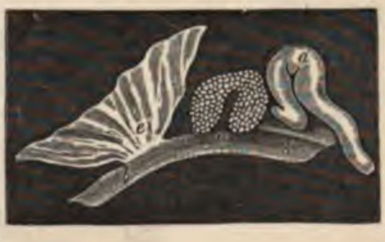


FIG. 458.

FIG. 457.—Diagram of part of digestive tract of a chick (fourth day). The black line represents hypoblast, the outer shading mesoblast: *l g*, lung diverticulum, with expanded end forming primary lung-vesicle; *S t*, stomach; *l*, two hepatic diverticula, with their terminations united by solid rows of hypoblast cells; *p*, diverticulum of the pancreas with the vesicular diverticula coming from it. (Gotte.)

FIG. 458.—Rudiments of the liver on the intestine of a chick at the fifth day of incubation. 1, heart; 2, intestine; 3, diverticulum of the intestine in which the liver (4) is developed; 5, part of the mucous layer of the germinal membrane. (Müller.)

Liver.—The liver is developed by the protrusion, as it were, of a part of the walls of the intestinal canal, in the form of two conical hollow branches which embrace the common venous stem (Figs. 457, 458). The outer part of these cones involves the omphalo-mesenteric vein, which breaks up in its interior into a plexus of capillaries, ending in venous trunks for the conveyance of the blood to the heart. The inner portion of the cones consists of a number of solid cylindrical masses of cells, derived probably from the hypoblast, which become gradually hollowed by the formation of the hepatic ducts, and among which blood-vessels are rapidly developed. The gland-cells of the organs are derived from the hypoblast, the connective tissue and vessels without doubt from the mesoblast. The gall-bladder is developed as a diverticulum from the hepatic duct. The spleen, lymphatic, and thymus glands are developed from the mesoblast: the thyroid partly also from the hypoblast which grows into it as a diverticulum from the fore-gut.

DEVELOPMENT OF THE RESPIRATORY APPARATUS.

The lungs, at their first development, appear as small tubercles or diverticular from the abdominal surface of the œsophagus.

The two diverticular at first open directly into the œsophagus, but as they grow, a separate tube (the future trachea) is formed at their point of fusion, opening into the œsophagus on its anterior surface. These primary diverticula of the hypoblast of the alimentary canal send off secondary branches into the surrounding mesoblast, and these again give off tertiary branches, forming the air-cells. Thus we have the lungs formed: the epithelium lining their air-cells, bronchi, and trachea being derived from the hypoblast, and all the rest of the lung-tissue, nerves, lymphatics, and blood-vessels, cartilaginous rings, and muscular fibres of the bronchi from the mesoblast. The diaphragm is early developed.

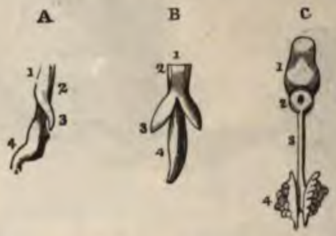


FIG. 459 illustrates the development of the respiratory organs. A, is the œsophagus of a chick on the fourth day of incubation, with the rudiments of the trachea on the lung of the left side, viewed laterally; 1, the inferior wall of the œsophagus; 2, the upper wall of the same tube; 3, the rudimentary lung; 4, the stomach. B, is the same object seen from below, so that both lungs are visible. C, shows the tongue and respiratory organs of the embryo of a horse: 1, the tongue; 2, the larynx; 3, the trachea; 4, the lungs, viewed from the upper side. (After Rathke.)

THE WOLFFIAN BODIES, URINARY APPARATUS, AND SEXUAL ORGANS.

The Wolffian bodies are organs peculiar to the embryonic state, and may be regarded as *temporary*, rather than *rudimental*, kidneys; for although they seem to discharge the functions of these latter organs, they are not developed into them.

Appearance of First Rudiments.—The Wolffian duct makes its appearance at an early stage in the history of the embryo, as a cord running longitudinally on each side in the mass of mesoblast, which lies just external to the protovertebræ (*ung*, Fig. 460). This cord, at first solid, becomes gradually hollowed out to form a tube (Wolffian duct) which sinks down till it projects beneath the lining membrane into the pleuro-peritoneal cavity.

The primitive tube thus formed sends off secondary diverticula at frequent intervals which grow into the surrounding mesoblast: tufts of vessels grow into the blind ends of these tubes, invaginating them and producing "Malpighian bodies" very similar in appearance to those of the permanent kidney, which constitute the substance of the Wolffian body.

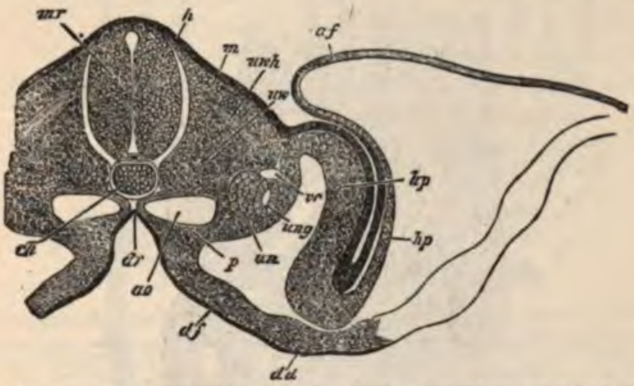


FIG. 460.—Transverse of embryo chick (third day). *m r*, rudimentary spinal cord; the primitive central canal has become constricted in the middle; *ch*, notochord; *uwh*, primordial vertebral mass; *m*, muscle-plate; *dr*, *df*, hypoblast and visceral layer of mesoblast lining groove, which is not yet closed in to form the intestines; *a o*, one of the primitive aortæ; *u n*, Wolffian body; *u n g*, Wolffian duct; *v c*, vena cardinalis; *h*, epiblast; *h p*, somatopleure and its reflection to form *a f*, amniotic fold; *p*, pleuro-peritoneal cavity. (Kölliker.)

Meanwhile another portion of mesoblast between the Wolffian body and the mesentery projects in the form of a ridge, covered on its free surface with epithelium termed "germ epithelium." From this projection is developed the reproductive gland (ovary or testis as the case may be).

Simultaneously, on the outer wall of the Wolffian body, between it and the body-wall on each side, an involution is formed from the pleuro-peritoneal cavity in the form of a longitudinal furrow, whose edges soon close over to form a duct (Müller's duct).

All the above points are shown in the accompanying figures, 460, 461, 462, 463.

The Wolffian bodies, or *temporary* kidneys, as they may be termed, give place at an early period in the human fœtus to their successors, the *permanent* kidneys, which are developed behind them. They diminish rapidly in size, and by the end of the third month have almost entirely disappeared. In connection, however, with their upper part, in the male, there are developed from a new mass of blastema, the *vasa efferentia, coni vasculosi,* and *globus major* of the epididymis; and thus is brought about a direct connection between the secreting part of the testicle and its duct (Cleland, Banks). The Wolffian *ducts* persist in the male, and are developed to form the body and globus minor of the epididymis, the vas deferens, and ejaculatory duct on each side, the vesiculæ seminales forming diverticula from their lower part. In the female a small relic of the Wolffian body persists as the "parovarium"; in the male a similar relic is termed the "organ of Giraldès." The lower end of the Wolffian duct remains in the female as the "duct of Gaertner," which descends toward, and is lost upon, the anterior wall of the vagina.

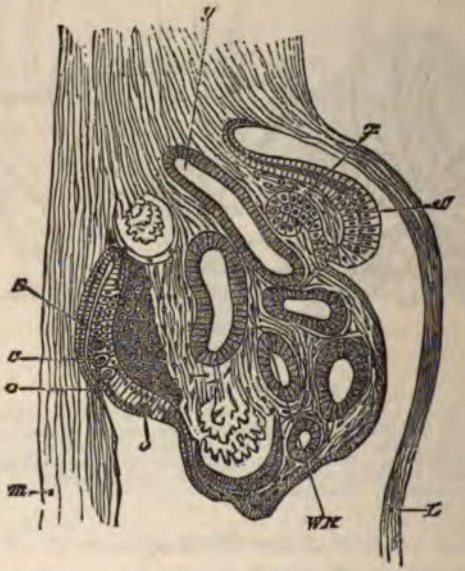


FIG. 461.—Section of intermediate cell-mass on the fourth day. *m*, mesentery; *L*, somatopleure; *a'*, germinal epithelium, from which *z*, the duct of Müller, becomes involuted; *a*, thickened part of germinal epithelium in which the primitive ova *C* and *o*, are lying; *E*, modified mesoblast, which will form the stroma of the ovary; *W K*, Wolffian body; *y*, Wolffian duct; × 160. (Waldeyer.)

From the lower end of the Wolffian duct a diverticulum grows back along the body of the embryo toward its anterior extremity, and ultimately forms the ureter. Secondary diverticula are given off from it and grow into the surrounding blastema of blood-vessels and cells.

Malpighian bodies are formed just as in the Wolffian body, by the invagination of the blind knobbed end of these diverticula by a tuft of vessels (Fig. 463). This process is precisely similar to the invagination of the primary optic vesicle by the rudimentary lens. Thus the kidney is developed, consisting at first of a number of separate *lobules;* this condition remaining throughout life in many of the lower animals, *e.g.,* seals and whales, and traces of this lobulation being visible in the human fœtus at birth. In the adult all the lobules are fused into a compact solid organ.

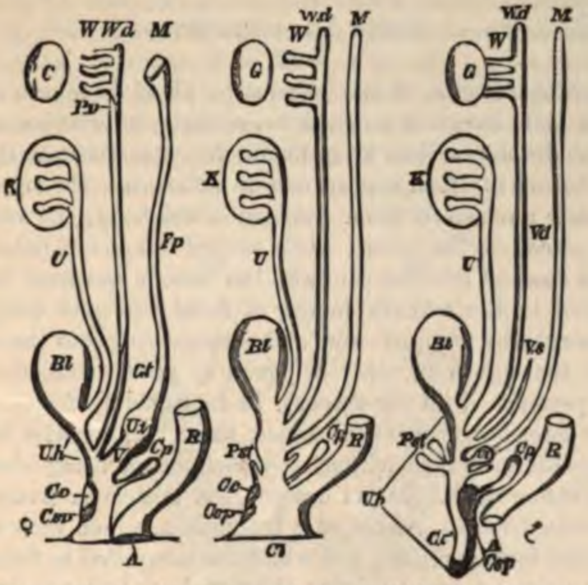


FIG. 462.—Diagrams showing the relations of the female (the left-hand figure ♀) and of the male (the right-hand figure ♂) reproductive organs to the general plan (the middle figure) of these organs in the higher vertebrata (including man). *C l*, cloaca; *R*, rectum; *B l*, urinary bladder; *U*, ureter; *K*, kidney; *U h*, urethra; *G*, genital gland, ovary or testis; *W*, Wolffian body; *W d*, Wolffian duct; *M*, Müllerian duct; *P s t*, prostate gland; *C p*, Cowper's gland; *C s p*, corpus spongiosum; *C c*, corpus cavernosum.

In the female.—*V*, vagina; *U t*, uterus; *F p*, Fallopian tube; *G t*, Gaertner's duct; *P v*, parovarium; *A*, anus; *C c*, *C s p*, clitoris.

In the male.—*C s p*, *C c*, penis; *Ut*, uterus masculinus; *V s*, vesicula seminalis; *V d*, vas deferens. (Huxley.)

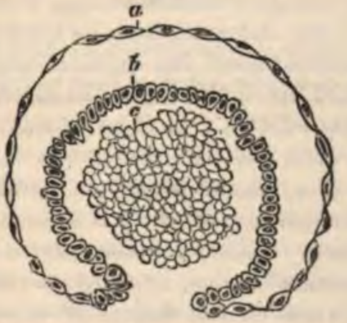


FIG. 463.—Transverse section of a developing Malpighian capsule and tuft (human). From a fœtus at about the fourth month; *a*, flattened cells growing to form the capsule; *b*, more rounded cells, continuous with the above, reflected round *c*, and finally enveloping it; *c*, mass of embryonic cells which will later become developed into blood-vessels. × 300. (W. Pye.)

The supra-renal capsules originate in a mass of mesoblast just above the kidneys; soon after their first appearance they are very much larger than the kidneys (see Fig. 464), but by the more rapid growth of the latter this relation is soon reversed.

LATER DEVELOPMENT.

The first appearance of the generative gland has been already described: for some time it is impossible to determine whether an ovary or testis will be developed from it; gradually however the special characters belonging to one of them appear, and in either case the organ soon begins to assume a relatively lower position in the body; the ovaries being ultimately placed in the pelvis; while toward the end of fœtal existence the testicles descend into the scrotum, the testicle entering the internal inguinal ring in the seventh month of fœtal life, and completing its descent through the inguinal canal and external ring into the scrotum by the end of the eighth month. A pouch of peritoneum, the *processus vaginalis*, precedes it in its descent, and ultimately forms the tunica vaginalis or serous covering of the organ; the communication between the tunica vaginalis and the cavity of the peritoneum being closed only a short time before birth. In its descent, the testicle or ovary of course retains the blood-vessels, nerves, and lymphatics, which were supplied to it while in the lumbar region, and which are compelled to follow it, so to speak, as it assumes a lower position in the body. Hence the explanation of the otherwise strange fact of the origin of these parts at so considerable a distance from the organ to which they are distributed.

Descent of the Testicles into Scrotum.—The means by which the descent of the testicles into the scrotum is effected are not fully and exactly known. It was formerly believed that a membranous and partly muscular cord, called the *gubernaculum testis*, which extends while the testicle is yet high in the abdomen, from its lower part, through the abdominal wall (in the situation of the inguinal canal) to the front of the pubes and lower part of the scrotum, was the agent by the contraction of which the descent was effected. It is now generally believed, however, that such is not the case; and that the descent of the testicle and ovary is rather the result of a general process of development in these and neighboring parts, the tendency of which is to produce this change in the relative position of these organs. In other words, the descent is not the result of a mere mechanical action, by which the organ is dragged down to a lower position, but rather one change out of many which attend the gradual development and re-arrangement of these organs. It may be repeated, however, that the details of the process by which the descent of the testicle into the scrotum is effected are not accurately known.

The homologue, in the female, of the gubernaculum testis, is a structure called the *round ligament of the uterus*, which extends through the inguinal canal, from the outer and upper part of the uterus to the subcutaneous tissue in front of the symphysis pubis.

At a very early stage of fœtal life, the Wolffian ducts, ureters, and Müllerian ducts, open into a receptacle formed by the lower end of the allantois, or rudimentary bladder; and as this communicates with the lower extremity of the intestine, there is for the time a common receptacle or *cloaca* for all these parts, which opens to the exterior of the body through a part corresponding with the future anus, an arrangement which is permanent in Reptiles, Birds, and some of the lower Mammalia.

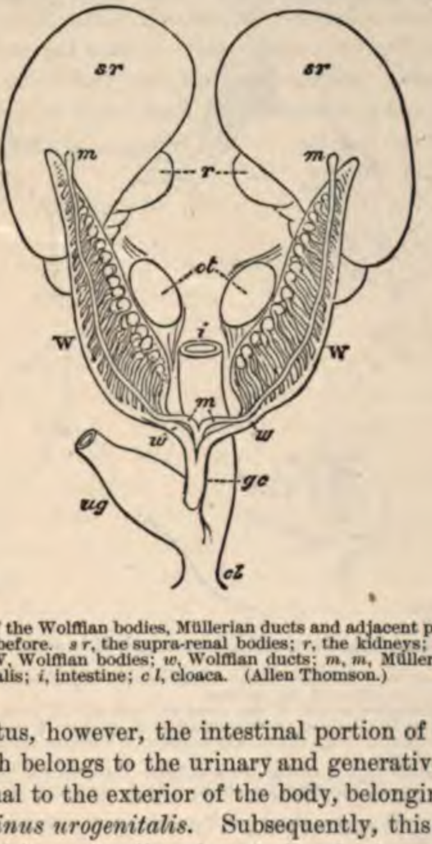
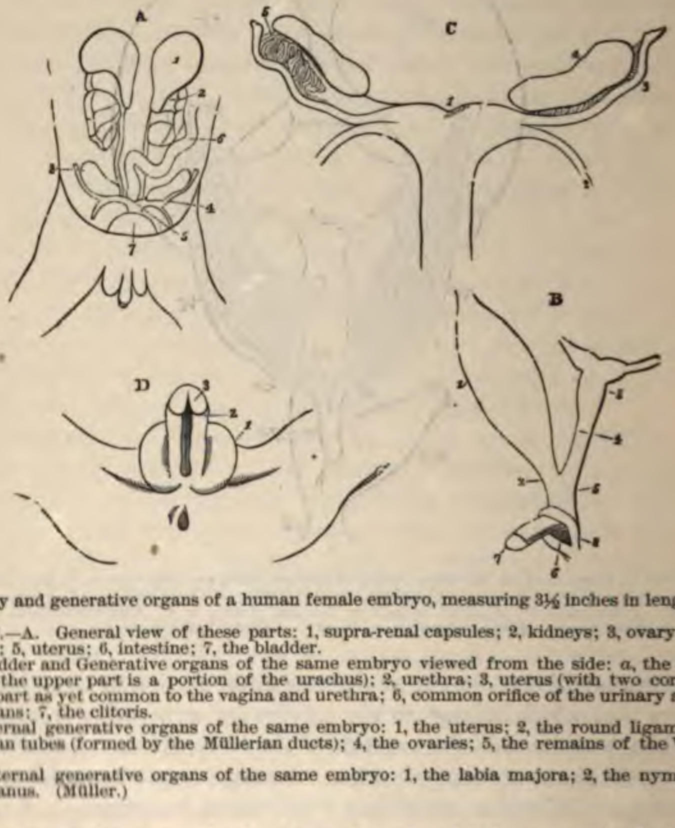


FIG. 464.—Diagram of the Wolffian bodies, Müllerian ducts and adjacent parts previous to sexual distinction, as seen from before. *s r*, the supra-renal bodies; *r*, the kidneys; *o t*, common blastema of ovaries or testicles; W, Wolffian bodies; *w*, Wolffian ducts; *m*, *m*, Müllerian ducts; *g c*, genital cord; *u g*, sinus urogenitalis; *i*, intestine; *c l*, cloaca. (Allen Thomson.)

In the human fœtus, however, the intestinal portion of the cloaca is cut off from that which belongs to the urinary and generative organs; a separate passage or canal to the exterior of the body, belonging to these parts, being called the *sinus urogenitalis*. Subsequently, this canal is divided, by a process of division extending from before backward or from above downward, into a "pars urinaria" and a "pars genitalis." The former, continuous with the *urachus*, is converted into the urinary bladder.

The Fallopian tubes, the uterus, and the vagina are developed from the Müllerian ducts (Fig. 464, *m*, and Fig. 465) whose first appearance has been already described. The two Müllerian ducts are united below into a single cord, called the *genital cord*, and from this are developed the vagina, as well as the cervix and the lower portion of the body of the uterus; while the ununited portion of the duct on each side forms the upper part of the uterus, and the Fallopian tube. In certain cases of arrested or abnormal development, these portions of the Müllerian ducts may not become fused together at their lower extremities, and there is left a cleft or horned condition of the upper part of the uterus resembling a condition which is permanent in certain of the lower animals.

In the male, the Müllerian ducts have no special function, and are but slightly developed. The hydatid of Morgagni is the remnant of the upper part of the Müllerian duct. The small prostatic pouch, *uterus masculinus*, or *sinus pocularis*, forms the atrophied remnant of the distal end of the genital cord, and is, of course, therefore, the homologue, in the male, of the vagina and uterus in the female.



Urinary and generative organs of a human female embryo, measuring 3½ inches in length.

FIG. 465.—A. General view of these parts: 1, supra-renal capsules; 2, kidneys; 3, ovary; 4, Fallopian tube; 5, uterus; 6, intestine; 7, the bladder.

B.—Bladder and Generative organs of the same embryo viewed from the side: *a*, the urinary bladder (at the upper part is a portion of the urachus); 2, urethra; 3, uterus (with two cornua); 4, vagina; 5, part as yet common to the vagina and urethra; 6, common orifice of the urinary and generative organs; 7, the clitoris.

C.—Internal generative organs of the same embryo: 1, the uterus; 2, the round ligaments; 3, the Fallopian tubes (formed by the Müllerian ducts); 4, the ovaries; 5, the remains of the Wolffian bodies.

D.—External generative organs of the same embryo: 1, the labia majora; 2, the nymphæ; 3, clitoris; 4, anus. (Müller.)

The external parts of generation are at first the same in both sexes. The opening of the genito-urinary apparatus is, in both sexes, bounded by two folds of skin, whilst in front of it there is formed a penis-like body surmounted by a glans, and cleft or furrowed along its under surface. The borders of the furrows diverge posteriorly, running at the sides of the genito-urinary orifice internally to the cutaneous folds just mentioned (see Figs. 465, 466, 467). In the female, this body becoming retracted, forms the clitoris, and the margins of the furrow on its under surface are converted into the nymphæ, or labia minora, the labia majora pudendæ being constituted by the great cutaneous folds. In the male fœtus, the margins of the furrow at the under surface of the penis unite at about the fourteenth week, and form that part of the urethra which is included in the penis. The large cutaneous folds form the scrotum, and later (in the eighth month of development), receive the testicles, which descend into them from the abdominal cavity. Sometimes the urethra is not closed, and the deformity called hypospadias then results. The appearance of hermaphroditism may, in these cases, be increased by the retention of the testes within the abdomen.

CHAPTER XXI.

ON THE RELATION OF LIFE TO OTHER FORCES.

An enumeration of theories concerning the nature of life would be beside the purpose of the present chapter. They are interesting as marks of the way in which various minds have been influenced by the mystery which has always hung about vitality; their destruction is but another warning that any theory we can frame must be considered only a tie for connecting present facts, and one that must yield or break on any addition to the number which it is to bind together.

Before attention had been drawn to the mutual convertibility of the various so-called physical forces—heat, light, electricity, and others—and until it had been shown that these, like the matter through which they act, are limited in amount, and strictly measurable; that a given quantity of one force can produce a certain quantity of another and no more; that a given quantity of combustible material can produce only a given quantity of steam, and this again only so much motive-power; it was natural that men's minds should be satisfied with the thought that vital force was some peculiar innate power, unlimited by matter, and altogether independent of structure and organization. The comparison of life to a flame is probably as early as any thought about life at all. And so long as light and heat were thought to be inherent qualities of certain material which perished utterly in their production, it is not strange that life also should have been reckoned some strange spirit, pent up in the germ, expending itself in growth and development, and finally declining and perishing with the body which it had inhabited.

With the recognition, however, of a distinct correlation between the physical forces, came as a natural consequence a revolution of the commonly accepted theories concerning life also. The dictum, so long accepted, that life was essentially independent of physical force began to be questioned.

As it is well-nigh impossible to give a definition of life that shall be short, comprehensive, and intelligible, it will be best, perhaps, to take its chief manifestations, and see how far these seem to be dependent on other forces in nature, and how connected with them.

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[1] This chapter is a reprint, with some verbal alterations, of an essay contributed to *St. Bartholomew's Hospital Reports*, 1867, by W. Morrant Baker.

Life manifests itself by Birth, Growth, Development, Decline and Death; and an idea of life will most naturally arise by taking these events in succession, and studying them individually, and in relation to each other.

When the embryo in a seed awakes from that state, neither life nor death, which is called dormant vitality, and, bursting its envelopes, begins to grow up and develop, it may be said that there is a birth. And so, when the chick escapes from the egg, and when any living form is, as the phrase goes, brought into the world. In each case, however, birth is not the beginning of life, but only the continuation of it under different conditions. To understand the beginning of life in any individual, whether plant or animal, existence must be traced somewhat further back, and in this way an idea gained concerning the nature of the germ, the development of which is to issue in birth.

The germ may be defined as that portion of the parent which is set apart with power to grow up into the likeness of the being from which it has been derived.

The manner in which the germ is separated from the parent does not here concern us. It belongs to the special subject of generation. Neither need we consider apart from others those modes of propagation, as fission and gemmation, which differ more apparently than really from the ordinary process typified in the formation of the seed or ovum. In every case alike, a new individual plant or animal is a portion of its parent: it may be a mere outgrowth or bud, which, if separated, can maintain an independent existence; it may be not an outgrowth but simply a portion of the parent's structure, which has been naturally or artificially cut off, as in the spontaneous or artificial cleaving of a polype; it may be the embryo of a seed or ovum, as in those cases in which the process of multiplication of different organs has reached the point of separation of the individual more or less completely into two sexes, the mutual conjugation of a portion of each of which, the sperm-cell and the germ-cell, is necessary for the production of a new being. We are so accustomed to regard the conjugation of the two sexes as necessary for what is called generation, that we are apt to forget that it is only gradually in the upward progress of development of the vegetable and animal kingdoms, that those portions of organized matter which are to produce new beings are allotted to two separate individuals. In the least developed forms of life, almost any part of the body is capable of assuming the characters of a separate individual; and propagation, therefore, occurs by fission or gemmation in some form or other. Then, in beings a little higher in rank, only a special part of the body can become a separate being, and only by conjugation with another special part. Still, there is but one parent; and this hermaphrodite-form of generation is the rule in the vegetable and least developed portion of the animal kingdom. At last, in all animals but the lowest, and in some plants, the portions of organized structure specialized for development after their mutual union into a new individual, are found on two distinct beings, which we call respectively male and female.

The old idea concerning the power of growth resident in the germ of the new being, thus formed in various ways, was expressed by saying that a store of dormant vitality was laid up in it, and that so long as no decomposition ensued, this was capable of manifesting itself and becoming active under the influence of certain external conditions. Thus, the dormant force supposed to be present in the seed or the egg was assumed to be the primary agent in effecting development and growth, and to continue in action during the whole term of life of the living being, animal or vegetable, in which it was said to reside. The influence of external forces—heat, light, and others—was noticed and appreciated; but these were thought to have no other connection with vital force than that in some way or other they called it into action, and that to some extent it was dependent on them for its continuance. They were not supposed to be correlated with it in any other sense than this.

Now, however, we are obliged to modify considerably our notions and with them our terms of expression, when describing the origin and birth of a new being.

To take, as before, the simplest case—a seed or egg. We must suppose that the heat, which in conjunction with moisture is necessary for the development of those changes which issue in the growth of a new plant or animal, is not simply an agent which so stimulates the dormant vitality in the seed or egg as to make it cause growth, but it is a force, which is itself transformed into chemical and vital power. The embryo in the seed or egg is a part which can transform heat into vital force, this term being a convenient one wherewith to express the power which particular structures possess of growing, developing, and performing other actions which we call vital.[1] Of course the embryo can grow only by taking up fresh material and incorporating it with its own structure, and therefore, it is surrounded in the seed or ovum with matter sufficient for nutrition until it can obtain fresh supplies from without. The absorption of this nutrient matter involves an expenditure of force of some kind or other, inasmuch as it implies the raising of simple to more complicated forms. Hence the necessity for heat or some other power before the embryo can exhibit any sign of life. It would be quite as impossible for the germ to begin life without external force as without a supply of nutrient matter. Without the force wherewith to take it, the matter would be useless. The heat, therefore, which in conjunction with moisture is necessary for the beginning of life, is partly expended as chemical power, which causes certain modifications in the nutrient material surrounding the embryo, *e.g.*, the transformation of starch into sugar in the act of germination; partly, it is transformed by the germ itself into vital force, whereby the germ is enabled to take up the nutrient material presented to it, and arrange it in forms characteristic of life. Thus the force is expended, and thus life begins—when a particle of organized matter, which has itself been produced by the agency of life, begins to transform external force into vital force, or, in other words, into a power by which it is enabled to grow and develop. This is the true beginning of life. The time of birth is but a particular period in the process of development, at which the germ, having arrived at a fit state for a more independent existence, steps forth into the outer world.

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[1] The term "vital force" is here employed for the sake of brevity. Whether it is strictly admissible will be discussed hereafter.

The general term *force* is used as synonymous with what is now often termed *energy*.

The term "dormant vitality," must be taken to mean simply the existence of organized matter with the *capacity* of transforming heat or other force into vital or growing power, when this force is applied to it under proper conditions.

The state of dormant vitality is like that of an empty voltaic battery, or a steam-engine in which the fuel is not yet lighted. In the former case no electric current passes, because no chemical action is going on. There is no transformation into electric force, because there is no chemical force to be transformed. Yet, we do not say, in this instance, that there is a store of electricity laid up in a dormant state in the battery; neither do we say that a store of motion is laid up in the steam-engine. And there is as little reason for saying there is a store of vitality in a dormant seed or ovum.

Next to the beginning of life, we have to consider how far its continuance by growth and development is dependent on external force, and to what extent correlated with it.

Mere growth is not a special peculiarity of living beings. A crystal, if placed in a proper solution, will increase in size and preserve its own characteristic outline; and even if it be injured, the flaw can be in part or wholly repaired. The manner of its growth, however, is very different from that of a living being, and the process as it occurs in the latter will be made more evident by a comparison of the two cases. The increase of a crystal takes place simply by the laying of material on the surface only, and is unaccompanied by any interstitial change. This is, however, but an accidental difference. A much greater one is to be found in the fact that with the growth of a crystal there is no decay at the same time, and proceeding with it side by side. Since there is no life there is no need of death—the one being a condition consequent on the other. During the whole life of a living being, on the other hand, there is unceasing change. At different periods of existence the relation between waste and repair is of course different. In early life the addition is greater than the loss, and so there is growth; the reconstructed part is better than it was before, and so there is development. In the decline of life, on the contrary, the renewal is less than the destruction, and instead of development there is degeneration. But at no time is there perfect rest or stability.

It must not be supposed, therefore, that life consists in the capability of resisting decay. Formerly, when but little or nothing was known about the laws which regulate the existence of living beings, it was reasonable enough to entertain such an idea; and, indeed, life was thought to be, essentially, a mysterious power counteracting that tendency to decay which is so evident when life has departed. Now, we know that so far from life preventing decomposition, it is absolutely dependent upon it for all its manifestations.

The reason of this is very evident. Apart from the doctrine of correlation of force, it is of course plain that tissues which do work must sooner or later wear out if not constantly supplied with nourishment; and the need of a continual supply of food, on the one hand, and, on the other, the constant excretion of matter which, having evidently discharged what was required of it, was fit only to be cast out, taught this fact very plainly. But although, to a certain extent, the dependence of vital power on supplies of matter from without was recognized and appreciated, the true relation between the demand and supply was not until recently thoroughly grasped. The doctrine of the correlation of vital with other forces was not understood.

To make this more plain, it will be well to take an instance of transformation of force more commonly known and appreciated. In the steam-engine a certain amount of force is exhibited as motion, and the immediate agent in the production of this is steam, which again is the result of a certain expenditure of heat. Thus, heat is in this instance said to be transformed into motion, or, in other language, one—molecular—mode of motion, heat, is made to express itself by another—mechanical—mode, ordinary movement. But the heat which produced the vapor is itself the product of the combustion of fuel, or, in other words, it is the correlated expression of another force—chemical, namely, that affinity of carbon and hydrogen for oxygen which is satisfied in the act of combustion. Again, the production of light and heat by the burning of coal and wood is only the giving out again of that heat and light of the sun which were used in their production. For, as it need scarcely be said, it is only by means of these solar forces that the leaves of plants can decompose carbonic acid, etc., and thereby provide material for the construction of woody tissue. Thus, coal and wood being products of the expenditure of force, must be taken to represent a certain amount of power; and, according to the law of the correlation of forces, must be capable of yielding, in some shape or other, just so much as was exercised in their formation. The amount of force requisite for rending asunder the elements of carbonic acid is exactly that amount which will again be manifested when they clash together again.

The sun, then, really, is the prime agent in the movement of the steam-engine, as it is indeed in the production of nearly all the power manifested on this globe. In this particular instance, speaking roughly, its light and heat are manifested successively as vital and chemical force in the growth of plants, as heat and light again in the burning fuel, and lastly by the piston and wheels of the engine as motive power. We may use the term transformation of force if we will, or say that throughout the cycle of changes there is but one force variously manifesting itself. It matters not, so that we keep clearly in view the notion that all force, so far at least as our present knowledge extends, is but a representative, it may be in the same form or another, of some previous force, and incapable, like matter, of being created afresh, except by the Creator. Much of our knowledge on this subject is of course confined to ideas, and governed by the words with which we are compelled to express them, rather than to actual things or facts; and probably the term force will soon lose the signification which we now attach to it. What is now known, however, about the relation of one force to another, is not sufficient for the complete destruction of old ideas; and, therefore, in applying the examples of transformation of physical force to the explanation of vital phenomena, we are compelled still to use a vocabulary which was framed for expressing many notions now obsolete.

The dependence of the lowest kind of vital existence on external force, and the manner in which this is used as a means whereby life is manifested, have been incidentally referred to more than once when describing the origin of vegetable tissues. The main functions of the vegetable kingdom are construction, and the perpetuation of the race; and the use which is made of external physical force is more simple than in animals. The transformation indeed which is effected, while much less mysterious than in the latter instance, forms an interesting link between animal and crystalline growth.

The decomposition of carbonic acid or ammonia by the leaves of plants may be compared to that of water by a galvanic current. In both cases a force is applied through a special material medium, and the result is a separation of the elements of which each compound is formed. On the return of the elements to their original state of union, there will be the return also in some form or other of the force which was used to separate them. Vegetable growth, moreover, with which we are now specially concerned, resembles somewhat the increase of unorganized matter. The accidental difference of its being in one case superficial, and in the other interstitial, is but little marked in the process as it occurs in the more permanent parts of vegetable tissues. The layers of lignine are in their arrangement nearly as simple as those of a crystal, and almost or quite as lifeless. After their deposition, moreover, they undergo no further change than that caused by the addition of fresh matter, and hence they are not instances of that ceaseless waste and repair which have been referred to as so characteristic of the higher forms of living tissue. There is, however, no contradiction here of the axiom, that where there is life there is constant change. Those parts of a vegetable organism in which active life is going on are subject, like the tissues of animals, to constant destruction and renewal. But, in the more permanent parts, life ceases with deposition and construction. Addition of fresh matter may occur, and so may decay also of that which is already laid down, but the two processes are not related to each other, and not, as in living parts, inter-dependent. Hence the change is not a vital one.

The acquirement in growth, moreover, of a definite shape in the case of a tree, is no more admirable or mysterious than the production of a crystal. That chloride of sodium should naturally assume the form of a cube is as inexplicable as that an acorn should grow into an oak, or an ovum into a man. When we learn the cause in the one case we shall probably in the other also.

There is nothing, therefore, in the products of life's more simple forms that need make us start at the notion of their being the products of only a special transformation of ordinary physical force, and we cannot doubt that the growth and development of animals obey the same general laws that govern the formation of plants. The connecting links between them are too numerous for the acceptance of any other supposition. Both kingdoms alike are expressions of vital force, which is itself but a term for a special transformation of ordinary physical force. The mode of the transformation is, indeed, mysterious, but so is that of heat into light, or of either into mechanical motion or chemical affinity. All forms of life are as absolutely dependent on external physical force as a fire is dependent for its continuance on a supply of fuel; and there is as much reason to be certain that vital force is an expression or representation of the physical forces, especially heat and light, as that these are the correlates of some force or other which has acted or is acting on the substances which, as we say, produce them.

In the tissues of plants, as just said, there is but little change, except such as is produced by additions of fresh matter. That which is once deposited alters but little; or, if the part be transient and easily perishable, the alteration is only or chiefly one produced by the ordinary process of decay. Little or no force is manifested; or, if it be, it is only the heat of the slow oxidation whereby the structure again returns to inorganic shape. There is no special transformation of force to which the term vital can be applied. With construction the chief end of vegetable existence has been attained, and the tissue formed represents a store of force to be used, but not by the being which laid it up. The labors of the vegetable world are not for itself, but for animals. The power laid up by the one is spent by the other. Hence the reason that the constant change, which is so great a character of life, is comparatively but little marked in plants. It is present, but only in living portions of the organism, and in these it is but limited. In a tree the greater part of the tissues may be considered dead; the only change they suffer is that fresh matter is piled on to them. They are not the seat of any transformation of force, and therefore, although their existence is the result of living action, they do not themselves live. Force is, so to speak, laid up in them, but they do not themselves spend it. Those portions of a vegetable organism which are doing active vital work—which are using the sun's light and heat as a means whereby to prepare building material, are, however, the seat of unceasing change. Their existence as living tissue depends upon this fact—upon their capability of perishing and being renewed.

And this leads to the answer to the question, What is the cause of the constant change which occurs in the living parts of animals and vegetables, which is so invariable an accompaniment of life, that we refuse the title of "living" to parts not attended by it? It is because all manifestations of life are exhibitions of power; and as no power can be originated by us, as, according to the doctrine of correlation of force, all power is but the representative of some previous force in the same or another form, so, for its production, there must be expenditure and change somewhere or other. For the vital actions of plants the light and heat of the sun are nearly or quite sufficient, and there is no need of expenditure of that store of force which is laid up in themselves; but with animals the case is different. They cannot directly transform the solar forces into vital power; they must seek it elsewhere. The great use of the vegetable kingdom is therefore to store up power in such a form that it can be used by animals; that so, when in the bodies of the latter, vegetable organized material returns to an inorganic condition, it may give out force in such a manner that it can be transformed by animal tissues, and manifested variously by them as vital power.

Hence, then, we must consider the waste and repair attendant on living growth and development as something more than these words, taken by themselves, imply. The waste is the return to a lower from a higher form of matter; and, in the fall, force is manifested. This force, when specially transformed by organized tissues, we call vital. In the repair, force is laid up. The analogy with ordinary transmutations of physical force is perfect. By the expenditure of heat in a particular manner a weight can be raised. By its fall heat is returned. The molecular motion is but the expression in another form of the mechanical. So with life. There is constant renewal and decay, because it is only so that vital activity can take place. The renewal must be something more than replacement, however, as the decay must be more than simple mechanical loss. The idea of life must include both storing up of force, and its transformation in the expenditure.

Hence we must be careful not to confound the mere preservation of individual form under the circumstances of concurrent waste and repair, with the essential nature of vitality.

Life, in its simplest form, has been happily expressed by Savory as a state of dynamical equilibrium, since one of its most characteristic features is continual decay, yet with maintenance for the individual by equally constant repair. Since, then, in the preservation of the equilibrium there is ceaseless change, it is not static equilibrium but dynamical.

Care must be taken, however, not to accept the term in too strict a sense, and not to confound that which is but a necessary attendant on life with life itself. For, indeed, strictly, there is no preservation of equilibrium during life. Each vital act is an advance toward death. We are accustomed to make use of the terms growth and development in the sense of progress in one direction, and the words decline and decay with an opposite signification, as if, like the ebb of the tide, there were after maturity a reversal of life's current. But, to use an equally old comparison, life is really a journey always in one direction. It is an ascent, more and more gradual as the summit is approached, so gradual that it is impossible to say when development ends and decline begins. But the descent is on the other side. There is no perfect equilibrium, no halting, no turning back.

The term, therefore, must be used with only a limited signification. There is preservation of the individual, yet, although it may seem a paradox, not of the same individual. A man at one period of his life may retain not a particle of the matter of which formerly he was composed. The preservation of a living being during growth and development is more comparable, indeed, to that of a nation, than of an individual as the term is popularly understood. The elements of which it is made up fulfil a certain work the traditions of which were handed down from their predecessors, and then pass away, leaving the same legacy to those that follow them. The individuality is preserved, but, like all things handed down by tradition, its fashion changes, until at last, perhaps, scarce any likeness to the original can be discovered. Or, as it sometimes happens, the alterations by time are so small that we wonder, not at the change, but the want of it. Yet, in both cases alike, the individuality is preserved, not by the same individual elements throughout, but by a succession of them.

Again, concurrent waste and repair do not imply of necessity the existence of life. It is true that living beings are the chief instances of the simultaneous occurrence of these things. But this happens only because the conditions under which the functions of life are discharged are the principal examples of the necessity for this unceasing and mingled destruction and renewal. They are the chief, but not the only instances of this curious conjunction.

A theoretical case will make this plain. Suppose an instance of some permanent structure, say a marble statue. If we imagine it to be placed under some external conditions by which each particle of its substance should waste and be replaced, yet with maintenance of its original size and shape, we obtain no idea of life. There is waste and renewal, with preservation of the individual form, but no vitality. And the reason is plain. With the waste of a substance like carbonate of calcium whose attractions are satisfied, there would be no evolution of force; and even if there were, no structure is present with the power to transform or manifest anew any power which might be evolved. With the repair, likewise, there would be no storing of force. The part used to make good the loss is not different from that which disappeared. There is therefore neither storing of force, nor its transformation, nor its expenditure; and therefore there is no life.

But real examples of the preservation of an individual substance under the circumstances of constant loss and renewal, may be found, yet without any semblance in them of life.

Chemistry, perhaps, affords some of the neatest and best examples of this. One, suggested by Shepard, seems particularly apposite. It is the case of trioxide of nitrogen (N_2O_3) in the preparation of sulphuric acid. The gas from which this acid is obtained is sulphur dioxide, and the addition of an equivalent of oxygen and the combination of the resulting sulphur trioxide (SO_3) with water (H_2O) is all that is required. Thus:

$$SO_2 \quad + \quad O \; + \; H_2O \; = \; H_2SO_4$$

Sulph. dioxide : Oxygen : Water = Sulphuric Acid.

Sulphur dioxide, however, cannot take the necessary oxygen directly from the atmosphere, but it can abstract it from trioxide of nitrogen (N_2O_3). when the two gases are mingled. The trioxide, accordingly, by continually giving up an equivalent of oxygen to an equivalent of sulphur dioxide, causes the formation of sulphuric acid, at the same time that it retains its composition by continually absorbing a fresh quantity of oxygen from the atmosphere.

In this instance, then, there is constant waste and repair, yet without life. And here an objection cannot be raised, as it might be to the preceding example, that both the destruction and repair come from without, and are not dependent on any inherent qualities of the substance with which they have to do. The waste and renewal in the last-named example are strictly dependent on the qualities of the chemical compound which is subject to them. It has but to be placed in appropriate conditions, and destruction and repair will continue indefinitely. Force, too, is manifested, but there is nothing present which can transform it into vital shape, and so there is no life.

Hence, our notion of the constant decay which, together with repair, takes place throughout life, must be not confined to any simply mechanical act. It must include the idea, as before said, of laying up of force, and its expenditure—its transformation too, in the act of being expended.

The growth, then, of an animal or vegetable, implies the expenditure of physical force by organized tissue, as a means whereby fresh matter is added to and incorporated with that already existing. In the case of the plant the force used, transformed, and stored up, is almost entirely derived from external sources; the material used is inorganic. The result is a tissue which is not intended for expenditure by the individual which has accumulated it. The force expended in growth by animals, on the other hand, cannot be obtained directly from without. For them a supply of force is necessary in the shape of food derived directly or indirectly from the vegetable kingdom. Part of this force-containing food is expended as fuel for the production of power; and the latter is used as a means wherewith to elaborate another portion of the food, and incorporate it as animal structure. Unlike vegetable structure, however, animal tissues are the seat of constant change, because their object is not the storing up of power, but its expenditure; so there must be constant waste; and if this happen, then for the continuance of life there must be equally constant repair. But, as before said, in early life the repair surpasses the loss, and so there is growth. The part repaired is better than before the loss, and thus there is development.

The definite limit which has been imposed on the duration of life has been already incidentally referred to. Like birth, growth, and development, it belongs essentially to living beings only. Dead structures and those which have never lived are subject to change and destruction, but decay in them is uncertain in its beginning and continuance. It depends almost entirely on external conditions, and differs altogether from the decline of life. The decline and death of living beings are as definite in their occurrence as growth and development. Like these they may be hastened or stayed, especially in the lower forms of life, by various influences from without; but the putting off of decline must be the putting off also of so much life; and, apart from disease, the reverse is true also. A living being starts on its career with a certain amount of work to do—various infinitely in different individuals, but for each well-defined. In the lowest members of both the animal and vegetable creation the progress of life in any given time seems to depend almost entirely on external circumstances; and at first sight it seems almost as if these lowly-formed organisms were but the sport of the surrounding elements. But it is only so in appearance, not in reality. Each act of their life is so much expended of the time and work allotted to them; and if, from absence of those surrounding conditions under which alone life is possible, their vitality is stayed for a time, it again proceeds on the renewal of the necessary conditions, from that point which it had already attained. The amount of life to be manifested by any given individual is the same, whether it takes a day or a year for its expenditure. Life may be of course at any moment interrupted altogether by disease and death. But supposing it, in any individual organism, to run its natural course, it will attain but the same goal, whatever be its rate of movement. Decline and death, therefore, are but the natural terminations of life; they form part of the conditions on which vital action begins; they are the end toward which it naturally tends. Death, not by disease or injury, is not so much a violent interruption of the course of life, as the attainment of a distant object which was in view from the commencement.

In the period of decline, as during growth, life consists in continued manifestations of transformed physical force; and there is of necessity the same series of changes by which the individual, though bit by bit perishing, yet by constant renewal retains its entity. The difference, as has been more than once said, is in the comparative extent of the loss and reproduction. In decline there is not perfect replacement of that which is lost. Repair becomes less and less perfect. It does not of necessity happen that there is any decrease of the quantity of material added in the place of that which disappears. But although the quantity may not be lessened, and may indeed absolutely increase, it is not perfect as material for repair, and although there may be no wasting, there is degeneration.

No definite period can be assigned as existing between the end of development and the beginning of decline, and chiefly because the two processes go on side by side in different parts of the same organism. The transition as a whole is therefore too gradual for appreciation. But, after some time, all parts alike share in the tendency to degeneration; until at length, being no longer able to subdue external force to vital shape, they die; and the elements of which they are composed simply employ what remnant of power, in the shape of chemical affinity, is still left in them, as a means whereby they may go back to the inorganic world. Of course the same process happens constantly during life; but in death the place of the departing elements is not taken by others.

Here, then, a sharp boundary line is drawn where one kind of action stops and the other begins; where physical force ceases to be manifested except as physical force, and where no further vital transformation takes place, or can in the body ever do so. For the notion of death must include the idea of impossibility of revival, as a distinction from that state of what is called "dormant vitality," in which, although there is no life, there is capability of living. Hence the explanation of the difference between the effect of appliance of external force in the two cases. Take, for examples, the fertile but not yet living egg, and the barren or dead one. Every application of force to the one must excite movement in the direction of development; the force, if used at all, is transformed by the germ into vital energy, or the power by which it can gather up and elaborate the materials for nutrition by which it is surrounded. Hence its freedom throughout the brooding time from putrefaction. In the other instance, the appliance of force excites only degeneration; if transformed at all, it is only into chemical force, whereby the progress of destruction is hastened; hence it soon rots. To the one, heat is the signal for development, to the other for decay. By one it is taken up and manifested anew, and in a higher form; to the other it gives the impetus for a still quicker fall.

Life, then, does not stand alone. It is but a special manifestation of transformed force. "But if this be so," it may be said—"if the resemblance of life to other forces be great, are not the differences still greater?"

At the first glance, the distinctions between living organized tissue and inorganic matter seem so great that the difficulty is in finding a likeness. And there is no doubt that these wide differences in both outward configuration and intimate composition have been mainly the causes of the delay in the recognition of the claims of life to a place among other forces. And reasonably enough. For the notion that a plant or an animal can have any kind of relationship in the discharge of its functions to a galvanic battery or a steam engine is sufficiently startling to the most credulous. But so it has been proved to be.

Among the distinctions between living and unorganized matter, that which includes differences in structure and proximate chemical composition has been always reckoned a great one. The very terms organic and inorganic were, until quite recently, almost synonymous with those which implied the influence of life and the want of it. The science of chemistry, however, is a great leveller of artificial distinctions, and many complex substances which, it was supposed, could not be formed without the agency of life, can be now made directly from their elements or from very simple combinations of these. The number of complex substances so formed artificially is constantly increasing; and there seems to be no reason for doubting that even such as albumin, gelatin, and the like, will be ultimately produced without the intermediation of living structure.

The formation of the latter, such an organized structure for instance as a cell or a muscular fibre, is a different thing altogether. There is at present no reason for believing that such will ever be formed by artificial means; and, therefore, among the peculiarities of living force-transforming agents, must be reckoned as a great and essential one, a special intimate structure, apart from mere ultimate or proximate chemical composition, to which there is no close likeness in any artificial apparatus, even the most complicated. This is the real distinction, as regards composition, between a living tissue and an inorganic machine; namely, the difference between the structural arrangement by which force is transformed and manifested anew. The fact that one agent for transforming force is made of albumen or the like, and another of zinc or iron, is a great distinction, but not so essential or fundamental a one as the difference in mechanical structure and arrangement.

In proceeding to consider the difference between what may be called the transformation-products of living tissue, and of an artificial machine, it will be well to take one of the simple cases first—the production of mechanical motion; and especially because it is so common in both.

In one we can trace the transformation. We know, as a fact, that heat produces expansion (steam), and by constructing an apparatus which provides for the application of the expansive power in opposite directions alternately, or by alternating contraction with expansion, we are able to produce motion so as to subserve an infinite variety of purposes. For the continuance of the motion there must be a constant supply of heat, and therefore of fuel.

In the production of mechanical motion by the alternate contractions of muscular fibres we cannot trace the transformation of force at all. We know that the constant supply of force is as necessary in this instance as in the other; and that the food which an animal absorbs is as necessary as the fuel in the former case, and is analogous with it in function. In what exact relation, however, the latent force in the food stands to the movement in the fibre, we are at present quite ignorant. That in some way or other, however, the transformation occurs, we may feel quite certain.

There is another distinction between the two exhibitions of force which must be noticed. It has been universally believed, almost up to the present time, that in the production of living force the result is obtained by an exactly corresponding waste of the tissue which produces it; that, for instance, the power of each contraction of a muscle is the exact equivalent of the force produced by the more or less complete descent of so much muscular substance to inorganic, or less complex organic shape; in other words,—that the immediate fuel which an animal requires for the production of force is derived from its own substance; and that the food taken must first be appropriated by, and enter into, the very formation of living tissue before its latent force can be transformed and manifested as vital power. And here, it might be said, is a great distinction between a living structure and a simply mechanical arrangement such as that which has been used for comparison; the fuel which is analogous to the food of a plant or animal does not, as in the case of the latter,, first form part of the machine which transforms its latent energy into another variety of power.

We are not, at present, in a position to deny that this is a real and great distinction between the two cases; but modern investigations in more than one direction lead to the belief that we must hesitate before allowing such a difference to be a universal or essential one. The experiments referred to seem conclusive in regard to the production of muscular power in greater amount than can be accounted for by the products of muscular waste excreted; and it may be said with justice, that there is no intrinsic improbability in the supposed occurrence of transformation of force, apart from equivalent nutrition and subsequent destruction of the transforming agent. Argument from analogy, indeed, would be in favor of the more recent theory as the likelier of the two.

Whatever may be the result of investigations concerning the relation of waste of living tissue to the production of power, there can be no doubt, of course, that the changes in any part which is the seat of vital action must be considerable, not only from what may be called "wear and tear," but, also, on account of the great instability of all organized structures. Between such waste as this, however, and that of an inorganic machine there is only the difference in degree, arising necessarily from diversity of structure, of elemental arrangement, and so forth. But the repair in the two cases is different. The capability of reconstruction in a living body is an inherent quality like that which causes growth in a special shape or to a certain degree. At present we know nothing really of its nature, and we are therefore compelled to express the fact of its existence by such terms as "inherent power," "individual endowment," and the like, and wait for more facts which may ultimately explain it. This special quality is not indeed one of living things alone. The repair of a crystal in definite shape is equally an "individual endowment," or "inherent peculiarity," of the nature of which we are equally ignorant. In the case, however, of an inorganic machine there is nothing of the sort, not even as in a crystal. Faults of structure must be repaired by some means entirely from without. And as our notion of a living being, say a horse, would be entirely altered if flaws in his composition were repaired by external means only; so, in like manner, would our idea of the nature of a steam-engine be completely changed had it the power of absorbing and using part of its fuel as matter wherewith to repair any ordinary injury it might sustain.

It is this ignorance of the nature of such an act as reconstruction which causes it to be said, with apparent reason, that so long as the term "vital force" is used, so long do we beg the question at issue—What is the nature of life? A little consideration, however, will show that the justice of this criticism depends on the manner in which the word "vital" is used. If by it we intend to express an idea of something which arises in a totally different manner from other forces—something which, we know not how, depends on a special innate quality of living beings, and owns no dependence on ordinary physical force, but is simply stimulated by it, and has no correlation with it—then, indeed, it would be just to say that the whole matter is merely shelved if we retain the term "vital force."

But if a distinct correlation be recognized between ordinary physical force and that which in various shapes is manifested by living beings; if it be granted that every act—say, for example, of a brain or muscle—is the exactly correlated expression of a certain quantity of force latent in the food with which an animal is nourished; and that the force produced either in the shape of thought or movement is but the transformed expression of external force, and can no more originate in a living organ without supplies of force from without, than can that organ itself be formed or nourished without supplies of matter;—if these facts be recognized, then the term used in speaking of the powers exercised by a living being is not of very much consequence. We have as much right to use the term "vital" as the words galvanic and chemical. All alike are but the expressions of our ignorance concerning the nature of that power of which all that we call "forces" are various manifestations. The difference is in the apparatus by which the force is transformed.

It is with this meaning that, for the present, the term "vital force" may still be retained when we wish shortly to name that combination of energies which we call life. For, exult as we may at the discovery of the transformation of physical force into vital action, we must acknowledge not only that, with the exception of some slight details, we are utterly ignorant of the process by which the transformation is effected; but, as well, that the result is in many ways altogether different from that of any other force with which we are acquainted.

It is impossible to define in what respects, exactly, vital force differs from any other. For while some of its manifestations are identical with ordinary physical force, others have no parallel whatsoever. And it is this mixed nature which has hitherto baffled all attempts to define life, and, like a Will-o'-the-wisp, has led us floundering on through one definition after another only to escape our grasp and show our impotence to seize it.

In examining, therefore, the distinctions between the products of transformations by a living and by an inorganic machine, we have first to recognize the fact, that while in some cases the difference is so faint as to be nearly or quite imperceptible, in others there seems not a trace of resemblance to be discovered.

In discussing the nature of life's manifestations—birth, growth, development, and decline—the differences which exist between them and other processes more or less resembling them, but not dependent on life, have been already briefly considered and need not be here repeated. It may be well, however, to sum up very shortly the particulars in which life as a manifestation of force differs from all others.

The mere acquirement of a certain shape by growth is not a peculiarity of life. But the power of developing into so composite a mass even as a vegetable cell is a property possessed by an organized being only. In the increase of inorganic matter there is no development. The minutest crystal of any given salt has exactly the same shape and intimate structure as the largest. With the growth there is no development. There is increase of size with retention of the original shape, but nothing more. And if we consider the matter a little we shall see a reason for this. In all force-transformers, whether living or inorganic, with but few exceptions—and these are, probably, apparent only—something more is required than homogeneity of structure. There seems to be a need for some mutual dependence of one part on another, some distinction of qualities, which cannot happen when all portions are exactly alike. And here lies the resemblance between a living being and an artificial machine. Both are developments, and depend for their power of transforming force on that mutual relation of the several parts of their structure which we call organization. But here, also, lies a great difference. The development of a living being is due to an inherent tendency to assume a certain form; about which tendency we know absolutely nothing. We recognize the fact, and that is all. The development of an inorganic machine—say an electrical apparatus—is not due to any inherent or individual property. It is the result of a power entirely from without; and we know exactly how to construct it.

Here, then, again, we recognize the compound nature of a living being. In structure it is altogether different from a crystal—in inherent capacity of growth into definite shape it resembles it. Again, in the fact of its organization it resembles a machine made by man: in capacity of growth it entirely differs from it. In regard, therefore, to structure, growth, and development, it has combined in itself qualities which in all other things are more or less completely separated.

That modification of ordinary growth and development called generation, which consists in the natural production and separation of a portion of organized structure, with power itself to transform force so as therewith to build up an organism like the being from which it was thrown off, is another distinctive peculiarity of a living being. We know of nothing like it in the inorganic world. And the distinction is the greater because it is the fulfilment of a purpose, toward which life is evidently, from its very beginning, constantly tending. It is as natural a destiny to separate parts which shall form independent beings as it is to develop a limb. Hence it is another instance of that carrying out of certain projects, from the very beginning in view, which is so characteristic of things living and of no other.

It is especially in the discharge of what are called the animal functions that we see vital force most strangely manifested. It is true that one of the actions included in this term—namely, mechanical movement—although one of the most striking, is by no means a distinctive one. For it must be remembered that one of the commonest transformations of physical force with which we are acquainted is that of heat into mechanical motion, and that this may be effected by an apparatus having itself nothing whatever to do with life. The peculiarity of the manifestation in an animal or vegetable is that of the organ by which it is effected, and the manner in which the transformation takes place, not in the ultimate result. The mere fact of an animal's possessing capability of movement is not more wonderful than the possession of a similar property by a steam engine. In both cases alike, the motion is the correlative expression of force latent in the food and fuel respectively; but in one case we can trace the transformation in the arrangement of parts, in the other we cannot.

The consideration of the products of the transformation of force effected by the nervous system would lead far beyond the limits of the present chapter. But although the relation of mind to matter is so little known that it is impossible to speak with any freedom concerning such correlative expressions of physical force as thought and nerve-products, still it cannot be doubted that they are as much the results of transformation of force as the mechanical motion caused by the contraction of a muscle. But here the mystery reaches its climax. We neither know how the change is effected, nor the nature of the product, nor its analogies with other forces. It is therefore better, for the present, to confess our ignorance, than, with the knowledge which we have lately gained, to build up rash theories, serving only to cause that confusion which is worse than error.

It may be said, with perfect justice, that even if the foregoing conclusions be accepted, namely, that all manifestations of force by living beings are correlative expressions of ordinary physical force, still the argument is based on the assumption of the existence of the apparatus which we call living organized matter, with power not only to use external force for its own use in growth, development, and other vital manifestations, but for that modification of these powers which consists in the separation of a part that shall grow up into the likeness of its parent, and thus continue the race. We are therefore, it may added, as far as ever from any explanation of the origin of life. This is of course quite true. The object of the present chapter, however, is only to deal with the relations of life, as it now exists, to other forces. The manner of creation of the various kinds of organized matter, and the source of those qualities, belonging to it, which from our ignorance we call inherent, are different questions altogeth

To say that of necessity the power to form living organized matter will never be vouchsafed to us, that it is only a mere materialist who would believe in such a possibility, seems almost as absurd as the statement that such inquiries lead of necessity to the denial of any higher power than that which in various forms is manifested as "force," on this small portion of the universe. It is almost as absurd, but not quite. For, surely, he who recognizes the doctrine of the mutual convertibility of all forces, vital and physical, who believes in their unity and imperishableness, should be the last to doubt the existence of an all-powerful Being, of whose will they are but the various correlative expressions; from whom they all come; to whom they return.

APPENDIX A.

THE CHEMICAL BASIS OF THE HUMAN BODY.

Of the sixty-four known chemical elements no less than seventeen have been found, in larger or smaller quantities, to form the chemical basis of the animal body.

The substances occurring in largest quantities are the non-metallic elements, Oxygen, Carbon, Hydrogen, and Nitrogen—oxygen and carbon making up altogether about 85 per cent. of the whole. The most abundant of the metallic elements are Calcium, Sodium, and Potassium.

The following table represents the relative proportion of the various elements.—(Marshall.)

Oxygen	72·0	Fluorine	·08
Carbon	13·5	Potassium	·026
Hydrogen	9·1	Iron	·01
Nitrogen	2·5	Magnesium	·0012
Calcium	1·3	Silicon	·0002
Phosphorus	1·15	(Traces of copper, lead, and aluminium)	
Sulphur	·1476		
Sodium	·1		
Chlorine	·085		100·

Compounds.—The elementary substances above-mentioned seldom occur free or uncombined in the animal body; but are nearly always united among themselves in various numbers, and in variable proportions to form "*compounds.*" Several elements have, however, been detected in small amount free; traces of uncombined *Oxygen* and *Nitrogen* have been found in the blood, and of *Hydrogen* as well as of *Oxygen* and *Nitrogen* in the intestinal canal.

Organic and Inorganic Compounds.—It was formerly thought that the more complex compounds built up by the animal or vegetable *organism* were peculiar, and could not be made artificially by chemists from their elements, and under this idea they were formed into a distinct class, termed *organic.* This idea has been given up, but the name is still in use, with a different signification. The term *organic* is now applied simply to the compounds of the element Carbon, irrespective of their complexity; chemists having found that these compounds are so numerous and important, and that they include all those to which the term *organic* was in former times exclusively given.

Characteristics of Organic Compounds.—The animal organic compounds are characterized as a rule by their *complexity*, for in the first place many elements enter into their composition, thereby distinguishing them from bodies such as water (H_2O), hydrochloric acid (HCl), and ammonia (NH_3), which may be taken as types of inorganic compounds. And again, because many atoms of the same element occur in each molecule. This latter fact no doubt explains also the reason of the *instability* of organic compounds.

Another great cause of the instability arises from the fact that many such compounds contain the element Nitrogen, which may be called negative or undecided in its affinities, and may be easily separated from combination with other elements.

Animal tissues, containing as they do these organic nitrogenous compounds, are extremely prone to undergo chemical decomposition, and this is especially the case since they also contain a large quantity of water, a condition most favorable for the breaking up of such substances. It is from this fact that in the consideration of the chemical basis of the body we meet with an extremely large number of decomposition products.

In treating of the various substances found in the animal organism it is convenient to adopt the division into—

1. *Organic* $\left\{ \begin{array}{l} \text{a. Nitrogenous.} \\ \text{b. Non-Nitrogenous.} \end{array} \right.$
2. *Inorganic.*

1. ORGANIC.

(*a*) *Nitrogenous bodies* take the chief part in forming the solid tissues of the body, and are found to a considerable extent in the circulating fluids (blood, lymph, chyle), the secretions and excretions. They contain often in addition to Carbon, Hydrogen, Nitrogen, and Oxygen, the elements Sulphur and Phosphorus; but although the composition of most of them is approximately known, no general rational formula can at present be given.

Several classes of animal nitrogenous bodies may be distinguished, and it is convenient to consider them under the following heads:—

(1.) Albuminoids or proteids.
(2.) Gelatinous substances.
(3.) Decomposition nitrogenous bodies.
(4.) Certain supposed nitrogenous bodies, the exact composition of which has not been made out.

(1.) *Albuminoids* or *Proteids* are the most important of the nitrogenous animal compounds, one or more of them entering as essential parts into the formation of all living tissue. In the lymph, chyle, and blood, they also exist abundantly. Their atomic formula is uncertain. Their composition may be taken as—

Carbon . .	from 51·5	to 54·5	
Hydrogen . .	" 6·9	" 7·3	
Nitrogen . .	" 15·2	" 17·	
Oxygen . .	" 20·9	" 23·5	
Sulphur . .	" ·3	" 2·	(Hoppe-Seyler.)

Physical Properties.—Proteids are all amorphous and non-crystallizable, so that they possess as a rule no power (or scarcely any) of passing through animal membranes. They are soluble, but undergo alteration in composition in strong acids and alkalies; some are soluble in water, others in neutral saline solutions, some in dilute acids and alkalies, few in alcohol or ether. Their solutions have a left-handed action on polarized light.

Chemical Properties.—Certain general reactions are given for proteids. They are a little varied in each particular case:—

i.—A solution boiled with strong nitric acid, becomes yellow, and this yellowness gets darker on addition of ammonia (xantho-proteic reaction).
ii.—With potassium ferrocyanide and acetic acid, they give a white precipitate.
iii.—With a trace of copper sulphate and an excess of potassium or sodium hydrate they give a purple coloration.
iv.—With Millon's reagent (mixed nitrate and nitrite of mercury?), they give a white or pinkish precipitate, becoming more pink on boiling.
v.—When boiled with sodium sulphate and acetic acid, a white precipitate is thrown down.

It is usual to place Proteids into the following sub-classes, thus:—

I.	II.	III.
NATIVE ALBUMINS.	DERIVED ALBUMINS.	GLOBULIN.
Egg-Albumin.	Acid-Albumin.	(a.) Globulin.
Serum-Albumin.	Alkali-Albumin.	(b.) Myosin.
	Casein.	(c.) Fibrinoplastic Globulin.
		(d.) Fibrinogen.
		(e.) Vitellin, etc.

IV.—FIBRIN. V.—PEPTONES. VI.—COAGULATED PROTEIDS.
VII.—LARDACEIN.

CLASSES OF PROTEIDS.

I. The **Native Albumins** are soluble in water and in saline solutions coagulable by heating, not precipitated by acetic or normal phosphoric acid. Serum-albumin (p. 85, Vol. I.) is distinguished from egg-albumin in being soluble in ether and in not so easily giving a precipitate with strong hydrochloric acid; the precipitate being easily redissolved in excess of the acid. Serum-albumin is found in the blood, lymph and serous and synovial fluids, and the tissues generally; it appears in the urine in the condition known as albuminuria. Two varieties, *metalbumin* and *paralbumin* have been described as existing in dropsical fluids and ovarian cysts respectively.

II. **Derived Albumins** are made by adding dilute acids or alkalies to solutions of native-albumin. They are insoluble in water or in neutral saline solutions, and are not coagulated by heat. Both the native-albumins and the next two classes (iii. and iv.) of proteids generally undergo change into either acid or alkali albumin on the addition of acids or alkalies, and foods containing either albumins or globulins change first of all into one or other of these compounds, according as they are acted upon by the gastric or pancreatic juices respectively. Acid-albumin is called also *syntonin,* and is either identical with or akin to it. Casein is very probably natural alkali-albumin, and exists in milk, being kept in solution by the alkaline phosphates; it exists also in the serum and serous fluids in small quantity, and in muscle. It is not coagulable by heat, and so corresponds with the other derived albumins; it is obtainable as a precipitate by neutralizing milk with acid (acetic). Naturally it is precipitated in sour milk, on the formation of lactic acid.

III. **Globulins** which comprise the fibrin-forming substances of the blood and the coagulable material in muscle, and also the principal part of the crystalline lens, yelk of egg, etc., are soluble in very dilute saline solutions, but not in distilled water like the native-albumins; on addition of an acid or alkali, they are converted into the corresponding derived-albumin. They are precipitated on heating. The following are the chief varieties of globulins.

(a.) *Globulin* or *Crystallin* is prepared by rubbing up the crystalline lens with sand, adding water and filtering. On passing a current of carbonic acid gas through the filtrate, globulin is precipitated. In properties, it resembles fibrino-plastin and fibrinogen, but cannot apparently produce fibrin in fluids containing either. It coagulates at 70°—75° C.

(b.) *Myosin* can be prepared (1) from dead muscle by removing all fat, tendon, etc., and washing repeatedly in water, until the washing contains no trace of proteids, and then treating with 10 per cent. solution of sodium chloride, which will dissolve a large proportion into a viscid fluid, which filters with difficulty. If the viscid filtrate be dropped little by little into a large quantity of distilled water, a white flocculent precipitate of myosin will occur. (2) Or from living muscle by freezing and rubbing up in a mortar with snow and sodium chloride solution 1 per cent., a fluid is obtained which on filtering is at first liquid, but will finally clot; the clot is myosin.

Myosin, on addition of dilute acids, dissolves and forms syntonin or acid-albumin. It is less soluble in dilute saline solutions than (*c*) and (*d*). It coagulates at 55°—60° C.

(c.) *Fibrinoplastin* or *fibrinoplastic globulin* or *paraglŏbulin* is prepared from blood-serum diluted with 10 vols. of water, by passing a current of carbonic acid gas, and collecting the fine precipitate which is formed, and washing with water containing carbonic acid gas. The current should be strong and not long continued. It may be better prepared as a sticky white substance, by saturating serum with crystallized sodium chloride or magnesium sulphate. (See also p. 69, Vol. I.) It coagulates at 68°—80° C.

(d.) *Fibrinogen* is prepared from hydrocele and other like fluids by diluting and passing a brisk current of carbonic acid gas (CO_2) through the solution; or by saturation of the nerve fluids with sodium chloride or magnesium sulphate. (See also p. 69, Vol. I.) It coagulates at 55°—57° C.

(e.) *Vitellin* can be prepared from yelk of egg, in which it is probably associated with lecithin.

IV. **Fibrin** is a white filamentous body formed in the spontaneous coagulation of certain animal fluids. It is insoluble in water, except at very high temperatures, soluble in dilute acids and alkalies to a slight degree, and in strong neutral saline solutions. Soluble also in strong acids and alkalies.

It is prepared by washing blood-clot or by whipping blood with a bundle of twigs. Its formation in the blood has been already fully considered.

V. **Peptones** (or albuminose) are nitrogenous bodies of uncertain composition made in the process of the digestion of other proteids. It is almost certain that there are several distinct forms.

The great distinction which exists between peptone and other proteids is their diffusibility and they giving no precipitates with either acids or alkalies, with copper sulphate, ferric chloride, potassium ferrocyanide and acetic acid, or on boiling, and only with picric acid, tannin, mercuric chloride, silver nitrate, and lead acetate. In addition to this the color which a peptone gives with potassium hydrate and cupric sulphate is reddish instead of violet.

Kühne believes that ordinary albumin splits up under the action of the gastric juice or pancreatic juice into two parts, one called *antialbumose*, and the other *hemialbumose*, and further that antialbumose becomes *antipeptone* and hemialbumose, *hemipeptone*. The difference between hemipeptone and antipeptone is that the former can be further split up by the action of the pancreatic juice. He believes that antialbumose is closely allied to syntonin, and that the hemialbumose is more like myosin, and if the pepsin be feebly acting, a body which he calls *antialbumate* appears, which cannot be converted into peptone by gastric juice, but can by pancreatic juice. Solutions of hydrochloric acid or of sulphuric acid can, under favorable circumstances, partially change albumin into peptone.

VI.—**Coagulated Proteids.**—When a native albumin or a globulin is raised to a certain temperature (varying a little with each substance), about 70° C, it undergoes coagulation and loses most of its original characters. It becomes insoluble both in water and in saline solutions, and although soluble in strong acids and alkalies in boiling, partially decomposes during the process. They are not soluble in dilute acids or alkalies, but dissolve freely under the action of the gastric or of the pancreatic secretion, being converted into peptones.

VII. **Lardacein.**—Lardacein or amyloid substance is found in certain organs of the body, chiefly in the liver, as a morbid deposit. It is insoluble in water, and in saline solutions. It is unacted upon by the digestive juices. It is colored red by iodine. It is soluble in acids or in alkalies, thus forming acid or alkali albumin.

(2.) *Gelatinous principles* include:—(1.) Gelatin; (2.) Mucin; (3.) Elastin; (4.) Chondrin; and (5.) Keratin. They are very like the Proteid group, but exhibit considerable differences among themselves.

(1.) *Gelatin* is produced by boiling fibrous tissue, or by treating bones with acids, whereby their salts are dissolved, leaving the framework of gelatin, which is soluble in hot water.

It is a yellow, amorphous, transparent body, which does not give any of the proteid reactions if pure, insoluble in cold, but soluble in hot water, forming a jelly on cooling. Its solutions are precipitated by tannin, by alcohol and by mercuric chloride.

(2.) *Mucin*, contained in mucus. It is a substance of ropy consistency.

Prepared from ox-gall by precipitation with alcohol, and afterward redissolving in water, and reprecipitating with acetic acid. It may be also prepared from diluting mucus with water, filtering, treating the insoluble portion with weak caustic alkali, and precipitating with acetic acid. It is precipitated by alcohol and mineral acids, but dissolved by excess of the latter—dissolved by alkalies. It gives the proteid reaction with Millon's reagent, but not with cupric sulphate and potassium hydrate. It is not precipitated by mercuric chloride or by tannic acid. It is a colloid substance.

(3.) *Elastin* is the basis of elastic tissue; it is soluble only in strong alkalies on boiling; strong sulphuric or nitric acid dissolves it in the cold.

(4.) *Chondrin* is contained in the matrix of hyaline cartilage, and may be extracted by boiling with water and precipitating with acetic acid.

(5.) *Keratin* is obtained from hair, nails, and dried skin. It contains sulphur, evidently only loosely combined.

(3.) *Decomposition Nitrogenous products.*—These are formed by the chemical actions which go on in digestion, secretion, and nutrition.

Most of the compounds are *amides*, which are acids in which *amidogen*, NH_2, is substituted for *hydroxyl*, OH. Amides may also be represented as obtained from the ammonium salts by abstraction of water, or as derived from one or more molecules of ammonia, NH_3, by substituting acid radicals for hydrogen. Thus *acetamide* may be written in any of the following ways:—

$$\begin{array}{l} CH_3 \\ CO\,NH_2 \end{array} \qquad \left.\begin{array}{l} CH_3 \\ CO\,ONH_4 \end{array}\right\} -H_2O$$

or

$$\left.\begin{array}{l} (C_2H_3O)' \\ H' \\ H' \end{array}\right\} N$$

(C_2H_3O) being the radical of acetic acid.

Varieties.—Several of the varieties of amides are represented in the products with which we have to do.

(a.) *Monamides* which are derived from a monatomic acid—that is to say, an acid which contains the carboxyl group COOH, once, by the substitution of NH_2 for OH in this group. In these compounds if only one is the H in NH_2 is replaced by an acid radical, a primary monamide of formed; if two, by acid or alcohol radicals, a secondary monamide; if three, by acid or alcohol radicals, a tertiary monamide.

Two monamides are also formed from each diatomic acid (*i.e.*, those which contain OH twice, once in the carboxyl group COOH, and once in the alcohol group $C_n H_{2n} OH$), both by the substitution of NH_2 for OH, and therefore having the same composition. They are isomeric and not identical however, the one formed by the substitution of NH_2 for the alcoholic OH being acid, while the other formed by the replacement of the basic hydroxyl is neutral. The acid amides are called *amic acids*, or may form a class by themselves, called *alanines*.

Three amides are obtained from each diatomic and bibasic acid:—(1.) An acid amide or amic acid, derived from the acid ammonium salt by abstraction of one molecule of water. (2.) A neutral monamide (or *imide*), derived by abstraction of two molecules of water from the ammonium salts. (3.) A neutral amide or (b) DIAMIDE, derived from the ammonium salt by abstraction of two molecules of water. Thus succinic acid gives:—

Succinamic Acid . . . . $C_2H_4 \left\{\begin{array}{l} CO\,NH_2 \\ CO\,OH \end{array}\right.$

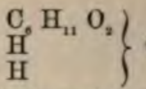
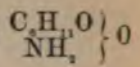
Succinimide . . . . $C_2H_4 \left\{\begin{array}{c} CO \\ CO \end{array}\right\} NH$

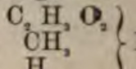
Succinamide . . . . $C_2H_4\ (CO\,NH_2)_2$

(*a*) PRIMARY MONAMIDES.

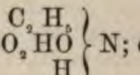
Glycin, glycocol or glycocin, or amido-acetic acid—

$\left.\begin{array}{l} C_2H_3O_2)' \\ H' \\ H' \end{array}\right\} N$ or $\left.\begin{array}{r} C_2H_3O \\ H_2 \end{array}\right\} O$ occurs in the body in combination, as in the biliary acids, never free. Glycocholic acid, when treated with weak acids, with alkalies, or with baryta water, splits up into cholic acid and glycin, or amido-acetic acid. Thus: $C_{26}H_{43}NO_6 + H_2O = C_{26}H_{40}O_5 + C_2H_5NO_2$. Glycocholic acid + water = cholic acid + glycin, and under similar circumstances Taurocholic acid splits up into cholic acid and taurin:—$C_{26}H_{45}O, NSO_7 + H_2O = C_{26}H_{40}O_5 + C_2H_7NSO_3$, or amido-isethionic. Taurocholic acid + water = cholic acid and taurin. Glycin occurs also in hippuric acid. It can be prepared from gelatin by the action of acids or alkalies; it can also be obtained from hippuric acid.

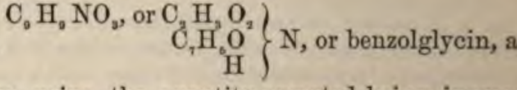
Leucin, or amido-caproic acid,  $\left.\begin{matrix}C_6H_{11}O_2\\H\\H\end{matrix}\right\}ON$, or  $\left.\begin{matrix}C_6H_{11}O\\NH_2\end{matrix}\right\}O$ occurs normally in many organs of the body and is a product of the pancreatic digestion of proteids. It is present in the urine in certain diseases of the liver in which there is loss of substance, especially in acute yellow atrophy. It occurs in circular oily discs or crystallizes in plates, and can be prepared either by boiling horn shavings, or any of the gelatins, with sulphuric acid, or out of the products of pancreatic digestion.

Sarcosin may be considered as methyl glycin,  $\left.\begin{matrix}C_2H_3O_2\\CH_3\\H\end{matrix}\right\}N$. It is a constituent of kreatin, but has never been found free in the human body.

Neurin ($C_5H_{13}NO$), is an unstable body, which has been found in ox and pig's gall.

Taurin, $C_2H_7NSO_3$ or  $SO_2\left.\begin{matrix}C_2H_5\\HO\\H\end{matrix}\right\}N$; or amido-isethionic acid, is a constituent of the bile acid, taurocholic acid, and is found also in traces in the muscles and lungs.—See above.

Cystin, $C_3H_7NSO_2$ occurs in a rare form of urinary calculus, which is only formed in a urine of neutral reaction. It can be crystallized in hexagonal laminæ of pale yellow color, becoming greenish on exposure to light.

Hippuric Acid,  $C_9H_9NO_3$, or $\left.\begin{matrix}C_2H_3O_2\\C_7H_5O\\H\end{matrix}\right\}N$, or benzolglycin, a normal constituent of human urine, the quantity excreted being increased by a vegetable diet, and therefore it is present in greater amount in the urine of herbivora. It may be decomposed by acids into glycin and benzoic acid. It crystallizes in semi-transparent rhombic prisms, almost insoluble in cold water, soluble in boiling water. (See also p. 361, Vol. I.)

Tyrosin, $C_9H_{11}NO_3$, is found, generally together with leucin, in certain glands, *e.g.*, pancreas and spleen; and chiefly in the products of pancreatic digestion or of the putrefaction of proteids. It is found in the urine in some diseases of the liver, especially acute yellow atrophy. It crystallizes in fine needles, which collect into feathery masses. It gives the proteid test with Millon's reagent, and heated with strong sulphuric acid, on the addition of ferric chloride gives a violet color.

Lecithin, $C_{42}H_{84}PNO_9$, is a phosphoretted fatty body, which has been found mixed with cerebrin, and oleophosphoric acid in the brain. It is also found in blood, bile and serous fluids, and in larger quantities in nerves, pus, yelk of egg, semen, and white blood-corpuscles. On boiling with acids it yields cholin, glycero-phosphoric acid, palmic and oleic acids.

Cerebrin, $C_{17}H_{33}NO_3$, is found in nerves, pus-corpuscles, and in the brain. Its chemical constitution is not known. It is a light amorphous powder, tasteless and odorless. Swells up like starch when boiled with water, and is converted by acids into a saccharine substance and other bodies. The so-called *Protagon* is a mixture of lecithin and cerebrin.

(*b*.) PRIMARY DIAMIDES OR UREAS.

Urea, $(NH_2)_2\,CO$, is the last product of the oxidation of the albuminous tissues of the body and of the albuminous foods. It occurs as the chief nitrogenous constituent of the urine of man, and of some other animals. It has been found in the blood and serous fluids, lymph, and in the liver.

Properties. Crystallizes in thin glittering needles, or in prisms with pyramidal ends. Easily soluble in water and alcohol, insoluble in ether, easily decomposed by strong acids, readily forms compounds with acids and bases, of which the chief are $(NH_2)_2\,COHNO_3$, *urea nitrate,* and $(NH_2)_2\,(CO)_2\,H_2\,C_2\,O_4 + H_2\,O$, *urea oxalate.*

Constitution.—It is usually considered to be a diamide of carbonic acid which may be written $\begin{array}{c} CO \\ H_2 \\ H_2 \end{array} N_2$, or $CO \left. \begin{array}{l} N\,H_2 \\ N\,H_2 \end{array} \right\}$ which is $CO\,(HO)_2$, with $(OH)'_2$, replaced by $(NH_2)'_2$. Some think it a monamide of carbamic acid, $CO,\ OH,\ NH_2$, thus $CO,\ NH_2\ NH_2$, with one atom of NH_2, or amidogen in place of one of hydroxyl OH.

Urea is isomeric with ammonium cyanate $C \left\{ \begin{array}{l} N \\ ONH_4 \end{array} \right.$ from which it was first artificially prepared.

Kreatin, $C_4\,H_9\,N_3\,O_2$, is one of the primary products of muscular disintegration. It is always found in the juice of muscle. It is generally decomposed in the blood into urea and kreatinin, and seldom, unless under abnormal circumstances, appears as such in the urine. Treated with either sulphuric or hydrochloric acid, it is converted into kreatinin; thus—

$$C_4\,H_9\,N_3\,O_2 = C_4\,H_7\,N_3\,O + H_2\,O.$$

Kreatinin, $C_4\,H_7\,N_3O$, is present in human urine, derived from oxidation of kreatin. It does not appear to be present in muscle.

(*c*.) UREIDES.

Ureides are a third variety of amides, and may be considered as ureas in which part of the hydrogen is replaced by diatomic acid radicals. *Monoureides* contain one acid radical and one urea residue; and *diureides,* one acid radical and two urea residues.

Uric Acid, $C\,H_4\,N_4\,O_3$, occurs in the urine, sparingly in human urine, abundantly in that of birds and reptiles, where it represents the chief, nitrogenous decomposition product. It occurs also in the blood, spleen, liver, and sometimes is the only constituent of urinary calculi. It is probably converted in the blood into urea and some carbon acid. It generally occurs in urine in combination with bases, forming *urates*, and never free unless under abnormal conditions. A deposit of urates may occur when the urine is concentrated or extremely acid, or when, as during febrile disorders, the conversion of uric acid into urea is incompletely performed.

Properties.—Crystallizes in many forms, of which the most common are smooth, transparent, rhomboid plates, diamond-shaped plates, hexagonal tables, etc. Very insoluble in water, and absolutely so in alcohol and ether. Dried with strong nitric acid in a water-bath, a compound is formed called *alloxan*, which gives a beautiful violet red with ammonium hydrate (*murexide*), and a blue color with potassium hydrate. It is easily precipitated from its solutions by the addition of a free acid. It forms both acid and neutral salts with bases. The most soluble urate is lithium urate.

Composition.—Very uncertain; has been however recently produced artificially, but it is not easily decomposed; it may be regarded as diureide of tartronic acid. The chief product of its decomposition is urea.

Guanin, $C_5 H_5 N_5 O$, has been found in the human liver, spleen, and fæces, but does not occur as a constant product.

Xanthin, $C_5 H_4 N_4 O_2$, has been obtained from the liver, spleen, thymus, muscle, and the blood. It is found in normal urine, and is a constituent of certain rare urinary calculi.

Hypoxanthin, $C_5 H_4 N_4 O$, *or sarkin*, is found in juice of flesh, in the spleen, thymus, and thyroid.

Allantoin, $C_4 H_6 N_4 O_3$, found in the allantoic fluid of the fœtus, and in the urine of animals for a short period after their birth. It is one of the oxidation products of uric acid, which on oxidation gives urea.

In addition to the amides and probably related to them, are certain coloring and excrementitious matters, which are also most likely distinct decomposition compounds.

PIGMENTS, ETC.

Bilirubin, $C_9H_9NO_2$, is the best known of the bile pigments. It is best made by extracting inspissated bile or gall stones with water (which dissolves the salts, etc.), then with alcohol, which takes out cholesterin, fatty, and biliary acids. Hydrochloric acid is then added, which decomposes the lime salt of bilirubin and removes the lime. After extracting with alcohol and ether, the residue is dried and finally extracted with chloroform. It crystallizes of a bluish-red color. It is allied in composition to hæmatin.

Biliverdin, $C_8H_9NO_2$, is made by passing a current of air through an alkaline solution of bilirubin, and by precipitation with hydrochloric acid. It is a green pigment.

Bilifuscin, $C_9H_{11}NO_3$, is made by treating gall stones with ether, then with dilute acid, and extracting with absolute alcohol. It is a non-crystallizable brown pigment.

Biliprasin is a pigment of a green color, which can be obtained from gall stones.

Bilihumin (Staedeler) is a dark brown earthy-looking substance, of which the formula is unknown.

Urobilin occurs in bile and in urine, and is probably identical with *stercobilin*, which is found in the fæces.

Uroerythrin is one of the coloring matters of the urine. It is orange red, and contains iron.

Melanin is a dark brown or black material containing iron, occurring in the lungs, bronchial glands, the skin, hair, and choroid.

Hæmatin has been fully treated of in Chapter IV.

Indican is supposed to exist in the sweat and urine. It has not, however, been satisfactorily isolated.

Indigo, $C_8 H_5 N O$, is formed from indican, and gives rise to the bluish color which is occasionally met with in the sweat and urine.

Indol, $C_7 H_2 N$, is found in the fæces, and is formed either by decomposition of indigo, or of the proteid food materials. It gives the characteristic disagreeable smell to fæces.

(4.) *Nitrogenous Bodies of Uncertain Nature.*

Ferments are bodies which possess the property of exciting chemical changes in matter with which they come in contact. They are at present divided into two classes, called (1) organized, and (2) unorganized or soluble. (1.) Of the *organized*, yeast may be taken as an example. Its activity depends upon the vitality of the yeast cell, and disappears as soon as the cell dies, neither can any substance be obtained from the yeast by means of precipitation with alcohol or in any other way which has the power of exciting the ordinary change produced by yeast.

(2.) *Unorganized or soluble ferments* are those which are found in secretions of glands, or are produced by chemical changes in animal or vegetable cells in general; when isolated they are colorless, tasteless, amorphous solids soluble in water and glycerin, and precipitated from the aqueous solutions by alcohol and acetate of lead. Chemically many of these are said to contain nitrogen.

Mode of action.—Without going into the theories of how these unorganized ferments act, it will suffice to mention that:

(1.) Their activity does not depend upon the actual amount of the ferment present. (2.) That the activity is destroyed by high temperature, and various concentrated chemical reagents, but increased by moderate heat, about 40° C. and by weak solutions of either an acid or an alkaline fluid. (3.) The ferments themselves appear to undergo no change in their own composition, and waste very slightly during the process.

Varieties.—The chief classes of unorganized ferments are:—

(1.) *Amylolytic*, which possess the property of converting starch into glucose. They add a molecule of water, and may be called hydrolytic. The probable reaction is as follows:

$$\underset{\text{Starch}}{3\,C_6H_{10}O_5} + \underset{\text{Water}}{3\,H_{20}} = \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Dextrin}}{C_6H_{10}O_5} = \underset{\text{Glucose.}}{3\,C_6H_{12}O_6}$$

This shows that there is an intermediate reaction, the starch being first turned only partly into glucose and principally into dextrin, which is afterward further converted into glucose. The principal amylolytic ferments are *Ptyalin,* found in the saliva, and a ferment, probably distinct in the pancreatic juice, called *Amylopsin.* These both act in an alkaline medium. Amylolytic ferments have been found in the blood and elsewhere.

Conversion of starch into sugar.—With reference to the action of the amylolytic ferments, recent observations have shown that the starch molecule is not by any means so simple as it has been represented above. As it is said that starchy materials, in the form of wheat and other cereals, and in the potato or its substitutes, form two-thirds of the total food of man, it is very important that we should note (1) the changes which occur in starch on cooking, and (2) the series of reactions it undergoes during its conversion by the amylolytic ferments into sugar.

(1.) The object of this change is to produce gelatinous or soluble starch. A starch granule consists of two parts: an envelope of *cellulose,* which gives a blue color with iodine on addition of sulphuric acid, and of *granulose,* which is contained within it, giving a blue with iodine alone. Brücke states that a third body is contained in the granule, which gives a red with iodine, viz., *erythro-granulose.* On boiling, the granulose swells up, bursts the envelope, and the whole granule is more or less completely converted into a paste or into mucilaginous gruel.

(2.) Changes which occur on addition of an amylolytic ferment. On the addition of saliva or extract of pancreas to gelatinous starch, the first change noticed is that the paste liquifies very quickly, but the liquid does not give the reaction for dextrin or for sugar; but soon this latter reaction appears, increasing very considerably and quickly, although at first, in addition, a reaction of erethrodextrin, a red on addition of iodine, is found; as the sugar increases, however, this disappears. At first the erythrodextrin is mixed with starch, as the reaction is a reddish purple with iodine, then it is a pure red, and finally a yellowish brown. As the sugar continues to increase the reaction with iodine disappears, but it is said that dextrin is still present in the form of achroo-dextrines, which give no reaction with iodine. However long the reaction goes on, it is unlikely that all the dextrin becomes sugar.

Next with regard to the kind of sugar formed, it is, at first at any rate, not *glucose* but *maltose,* the formula for which is $C_{12}H_{22}O_{11}$. Maltose is allied to saccharose or cane sugar more nearly than to glucose; it is crystalline; its solution has the property of polarizing light to a greater degree than solutions of glucose; is not so sweet, and reduces copper sulphate less easily. It can be converted into glucose by boiling with dilute acids.

According to Brown and Heron the reactions may be represented thus:—

One molecule of gelatinous starch is converted into *n* molecules of soluble starch.

One molecule of soluble starch$=10\ (C_{12}\ H_{20}\ O_{10})+8\ (H_2\ O)$
= 1 Erythro-dextrin (giving red with iodide) Maltose.
$9\ (C_{12}\ H_{20}\ O_{10}) + (C_{12}\ H_{22}\ O_{11})$
= 2. Erythro-dextrin (giving yellow with iodine) Maltose.
$8\ (C_{12} H_{20} C_{10}) + 2\ (C_{12}\ H_{22}\ C_{11})$
= 3. Achroo-dextrin Maltose.
$7\ (C_{12}\ H_{20}\ O_{10}) + 3\ (C_{12}\ H_{22}\ O_{11})$

And so on; the resultant being:—

$$\underset{\text{Soluble starch}}{10\ (C_{12}\ H_{20}\ O_{10})} + \underset{\text{Water}}{8\ (H_2\ O)} = \underset{\text{Maltose}}{8\ (C_{12}\ H_{22}\ O_{11})} + \underset{\text{Achroo-dextrin.}}{2\ (C_{12}\ \dot{H}_{20}\ O_{10})}$$

Pancreatic juice and intestinal juice are able to turn the achroo-dextrin which remains into maltose, and maltose into glucose (dextrose). It is doubtful whether saliva possesses the same power.

(2.) *Proteolytic* convert proteids into peptones. The nature of their action is probably hydrolytic. The proteolytic ferments of the body are called *Pepsin,* acting in an acid medium from the gastric juice. *Trypsin,* acting in an alkaline medium from the pancreatic juice. The Succus entericus is said to contain a third such ferment.

(3.) *Inversive,* which convert cane sugar or *saccharose* into grape sugar or *glucose.* Such a ferment was found by Claude Bernard in the Succus entericus; and probably exists also in the stomach mucus.

$$\underset{\text{Saccharose}}{2\ C_{12}\ H_{22}\ O_{11}} + \underset{\text{Water}}{2\ H_2\ O} = \underset{\text{Dextrose}}{C_{12}\ H_{24}\ O_{12}} + \underset{\text{Lævulose.}}{C_{12}\ H_{24}\ O_{12}}$$

(4.) *Ferments which act upon fats;* such a body called *Steapsin* has been found in pancreatic juice.

The ferments *Amylopsin, Trypsin,* and *Steapsin,* are said to exist separately in pancreatic juice, and if so, make up what was formerly called *Pancreatin* and which was said to have the functions of the three.

(5.) *Milk-curdling ferments.* It has been long known that rennet, a decoction of the fourth stomach of a calf, in brine, possessed the power of curdling milk. This power does not depend upon the acidity of the gastric juice, since the curdling will take place in a neutral or alkaline medium; neither does it depend upon the *pepsin,* as pure pepsin scarcely curdles milk at all, and the rennet which rapidly curdles milk has a very feeble proteolytic action. From this and other evidence it is believed that a distinct milk-curdling ferment exists in the stomach. W. Roberts has shown that a similar but distinct ferment exists in pancreatic extract, which acts best in an alkaline medium, next best in an acid medium, and worst in a neutral medium. The ferment of rennet acts best in an acid medium, and worst in an alkaline, the reaction ceasing if the alkalinity be more than slight.

In addition to the above ferments, many others most likely exist in the body, of which the following are the most important:

6. Fibrin-forming ferment (Schmidt), (see p. 69, *et seq.*, Vol. I.) found in the blood, lymph and chyle.

7. A ferment which converts glycogen into glucose in the liver; being therefore an amylolytic ferment.

8. Urinary ferments.

(*b.*) *Organic non-nitrogenous bodies* consist of—(1.) Oils and fats. (2.) Amyloids. (3.) Acids.

(1.) OILS AND FATS.

Saponifiable.		Non-saponifiable.	
Palmitin	$C_{51}H_{98}O_6$	Cholesterin	$C_{20}H_{44}O$
Stearin	$C_{57}H_{110}O_6$	Stercorin	?
Olein	$C_{57}H_{104}O_6$	Excretin	$O_{78}H_{156}SO_2$

Constitution.

The Saponifiable fats are formed by the union of fatty acid radicals with the triatomic alcohol, *Glycerin* $C_3 H_5 (OH)_3$. The radicals are $C_{18} H_{35}O$, $C_{16} H_{31} O$, and $C_{18} H_{33} O$, respectively. Human fat consists of a mixture of *palmitin*, *stearin*, and *olein*, of which the two former contribute three-quarters of the whole. Olein is the only liquid constituent.

General characteristics.—Insoluble in water and in cold alcohol; soluble in hot alcohol, ether, and chloroform. Colorless and tasteless; easily decomposed or saponified by alkalies or superheated steam into glycerin and the fatty acids.

Non-Saponifiable.—*Cholesterin*, $C_{26} H_{44} O$, is the only alcohol which has been found in the body in a free state. It occurs in small quantities in the blood and various tissues, and forms the principal constituent of gall-stones. It is found in dropsical fluids, especially in the contents of cysts, in disorganized eyes, and in plants (especially peas and beans). It is soluble in ether, chloroform, or benzol. It crystallizes in white feathery needles. See also under the head of the constituents of the bile.

Excretin (Marcet), and *Stercorin* (Flint), are crystalline fatty bodies which have been isolated from the fæces.

(2.) AMYLOIDS.

Amyloids.—Under this head are included both starch and sugar. The substances, like the fats, contain carbon, hydrogen, and oxygen; but the last-named element is present in much larger relative amount, the hydrogen and oxygen being in the proportion to form water.

The following varieties of these substances are found in health in the body.

(*a*) *Glycogen* ($C_6 H_{10} O_5$).—This substance, which is identical in composition with starch, and like it, is readily converted into sugar by ferments, is found in many embryonic tissues and in all new formations where active cell-growth is proceeding. It is present also in the placenta. After birth it is found almost exclusively in the liver and muscles.

Glycogen is formed chiefly from the saccharine matters of the food; but although its amount is much increased when the diet largely consists of starch and sugar, these are not its only source. It is still formed when the diet is flesh only, by the decomposition, probably, of albumin into glycogen and urea.

The destination of glycogen has been considered in a former chapter. (See p. 282, Vol. I.)

(*b*) *Glucose* or *grape sugar* ($C_6 H_{12} O_6 + H_2 O$) is found in minute quantities in the blood and liver, and occasionally in other parts of the body. It is derived directly from the starches and sugars in the food, or from the glycogen which has been formed in the body from these or other matters. However formed, it is in health quickly burnt off in the blood by union with oxygen, and thus helps in the maintenance of the body's temperature. Like other amyloids it is one source whence fat is derived.

(*c*) *Lactose* or *sugar of milk* ($C_{12} H_{22} O_{11} + H_2 O$), is formed in large quantity when the mammary glands are in a condition of physiological activity,—human milk containing 5 or 6 per cent. of it. Like other sugars it is a valuable nutritive material, and hence is only discharged from the body when required for the maintenance of the offspring. The same remark is applicable to the other organic nutrient constituents of the milk, albumin and saponifiable fats, which, if we except what is present in the secretions of the generative organs, are discharged from the body only under the same conditions and in the same secretion.

(*d*) *Inosite* ($C_6H_{12} O_6 + 2 H_2 O$), a variety of sugar, identical in composition with glucose, but differing in some of its properties, is found constantly in small amount in muscle, and occasionally in other tissues. Its origin and uses in the economy are, presumably, similar to those of glycogen.

(*e*) *Maltose* ($C_{12} H_{22} O_{11}$), is formed in the conversion of starch into glucose (see p. 336, Vol. II.).

(3.) ORGANIC ACIDS.

Group I.—Monatomic Fatty Acids.

Formic	$C\ HO\ \ OH$	Caproic	$C_6\ H_{11}\ O\ OH$
Acetic	$C_2\ H_3\ O\ OH$	Capric	$C_8\ H_{15}\ O\ OH$
Propionic	$C_3\ H_5\ O\ OH$	Palmitic	$C_{16}\ H_{31}\ O\ OH$
Butyric	$C_4\ H_7\ O\ OH$	Stearic	$C_{18}\ H_{35}\ O\ OH$
Valerianic	$C_5\ H_9\ O\ OH$	Oleic	$C_{18}\ H_{33}\ O\ OH$

Formic, acetic, and propionic acids are present in sweat, but normally in no other human secretion. They have been found elsewhere in diseased conditions. Butyric acid is found in sweat. Various others of these acids have been obtained from blood, muscular juice, fæces, and urine.

Group II.—Diatomic Fatty Acids.

Monobasic.		Bibasic.	
Glycolic	$C_2 H_4 O_3$	Oxalic	$C_2 H_2 O_4$
Lactic	$C_3 H_6 O_3$	Succinic	$C_4 H_6 O_4$
Leucic	$C_6 H_{12} O_3$	Sebacic	$C_{10} H_{10} O_4$

Lactic acid exists in a free state in muscular plasma, and is increased in quantity by muscular contraction, is never contained in healthy blood, and when present in abnormal amount seems to produce rheumatism.

Oxalates are present in the urine in certain diseases, and after drinking certain carbonated beverages, and after eating rhubarb, etc.

AROMATIC SERIES.

Benzoic	$C_7 H_6 O_2$
Phenol	$C_6 H_6 O$

Benzoic acid is always found in the urine of herbivora, and can be obtained from stale human urine. It does not exist free elsewhere.

Phenol.—Phenyl alcohol or *carbolic acid* exists in minute quantity in human urine. It is an alcohol of the aromatic series.

2. INORGANIC PRINCIPLES.

The inorganic proximate principles of the human body are numerous. They are derived, for the most part, directly from food and drink, and pass through the system unaltered. Some are, however, decomposed on their way, as chloride of sodium, of which only four-fifths of the quantity ingested are excreted in the same form; and some are newly formed within the body,—as for example, a part of the sulphates and carbonates, and some of the water.

Much of the inorganic saline matter found in the body is a necessary constituent of its structure,—as necessary in its way as albumin or any other organic principle; another part is important in regulating or modifying various physical processes, as absorption, solution, and the like; while a part must be reckoned only as matter, which is, so to speak, accidentally present, whether derived from the food or the tissues, and which will, at the first opportunity, be excreted from the body.

Gases.—The gaseous matters found in the body are *Oxygen*, *Hydro-*

gen, *Nitrogen*, *Carburetted* and *Sulphuretted hydrogen*, and *Carbonic acid*. The first three have been referred to (p. 325, Vol. II.). Carburetted and sulphuretted hydrogen are found in the intestinal canal. Carbonic acid is present in the blood and other fluids, and is excreted in large quantities by the lungs, and in very minute amount by the skin. It will be specially considered in the chapter on Respiration.

Water, the most abundant of the proximate principles, forms a large proportion,—more than two-thirds of the weight of the whole body. Its relative amount in some of the principal solids and fluids of the body is shown in the following table (quoted by Dalton, from Robin and Verdeil's table, compiled from various authors):—

QUANTITY OF WATER IN 1000 PARTS.

Teeth	100	Bile	880
Bones	130	Milk	887
Cartilage	550	Pancreatic juice	900
Muscles	750	Urine	936
Ligament	768	Lymph	960
Brain	789	Gastric juice	975
Blood	795	Perspiration	986
Synovia	805	Saliva	995

Uses of the Water of the Body.—The importance of water as a constituent of the animal body may be assumed from the preceding table, and is shown in a still more striking manner by its withdrawal. If any tissue—as muscle, cartilage, or tendon—be subjected to heat sufficient to drive off the greater part of its water, all its characteristic physical properties are destroyed; and what was previously soft, elastic, and flexible, becomes hard and brittle, and horny, so as to be scarcely recognizable.

In all the fluids of the body—blood, lymph, etc., water acts the part of a general solvent, and by its means alone circulation of nutrient matter is possible. It is the medium also in which all fluid and solid aliments are dissolved before absorption, as well as the means by which all, except gaseous, excretory products are removed. All the various processes of secretion, transudation, and nutrition, depend of necessity on its presence for their performance.

Source.—The greater part, by far, of the water present in the body is taken into it as such from without, in the food and drink. A small amount, however, is the result of the chemical union of hydrogen with oxygen in the blood and tissues. The total amount taken into the body every day is about 4½ lbs.; while an uncertain quantity (perhaps ½ to ¾ lb.) is formed by chemical action within it. (Dalton.)

Loss.—The loss of water from the body is intimately connected with excretion from the lungs, skin, and kidneys, and, to a less extent, from the alimentary canal. The loss from these various organs may be thus apportioned (quoted by Dalton from various observers).

From the Alimentary Canal (fæces) . .	4 per cent.
" Lungs	20 "
" Skin (perspiration) . . .	30 "
Kidneys (urine)	46 "
	100

Sodium and Potassium Chlorides are present in nearly all parts of the body. The former seems to be especially necessary, judging from the instinctive craving for it on the part of animals in whose food it is deficient, and from the diseased condition which is consequent on its withdrawal. In the blood, the quantity of chloride of sodium is greater than that of all its other saline ingredients taken together. In the muscles, on the other hand, the quantity of chloride of sodium is less than that of the chloride of potassium.

Calcium Fluoride, in minute amount, is present in the bones and teeth, and traces have been found in the blood and some other fluids.

Calcium, Potassium, Sodium, and Magnesium Phosphates are found in nearly every tissue and fluid. In some tissues—the bones and teeth—the phosphate of calcium exists in very large amount, and is the principal source of that hardness of texture on which the proper performance of their functions so much depends. The phosphate of calcium is intimately incorporated with the organic basis or matrix, but it can be removed by acids without destroying the general shape of the bone; and, after the removal of its inorganic salts, a bone is left soft, tough, and flexible.

Potassium and sodium phosphates with the carbonates, maintain the alkalinity of the blood.

Calcium Carbonate occurs in bones and teeth, but in much smaller quantity than the phosphate. It is found also in some other parts. The small concretions of the internal ear (otoliths) are composed of crystalline carbonate of calcium, and form the only example of inorganic crystalline matter existing as such in the body.

Potassium and Sodium Carbonates are found in the blood, and some other fluids and tissues.

Potassium, Sodium, and Calcium Sulphates are met with in small amount in most of the solids and fluids.

Silicon.—A very minute quantity of *silica* exists in the urine, and in the blood. Traces of it have been found also in bones, hair, and some other parts.

Iron.—The especial place of *iron* is in hæmoglobin, the coloring-matter of the blood, of which a further account has been given with the chemistry of the blood. Peroxide of iron is found, in very small quantities, in the ashes of bones, muscles, and many tissues, and in lymph and chyle, albumin of serum, fibrin, bile, and other fluids; and a salt of iron, probably a phosphate, exists in the hair, black pigment, and other deeply colored epithelial or horny substances.

Aluminium, Manganese, Copper, and Lead.—It seems most likely that in the human body, *copper*, *manganesium*, *aluminium* and *lead* are merely accidental elements, which, being taken in minute quantities with the food, and not excreted at once with the fæces, are absorbed and deposited in some tissue or organ, of which, however, they form no necessary part. In the same manner, *arsenic*, being absorbed, may be deposited in the liver and other parts.

APPENDIX B.

MEASURES OF WEIGHT (*Avoirdupois*).

(*Averages.*)

		lbs.	ozs.
Recent Skeleton		21	8
Muscles and Tendons		77	8
Skin and Subcutaneous tissue		16	5
Blood		11 to 14	–
Brain	Cerebrum	2	12
	Cerebellum	–	5¼
	Pons and Medulla oblongata	–	1
	Encephalon	3	2¼
Eyes		–	½
Heart		–	10
Intestines, small		1	11½
" large		1	1
Kidneys (both)		–	10½
Larynx, Trachea, and larger Bronchi		–	

	lbs.	ozs.
Liver	3	8
Lungs (both)	2	10
Œsophagus	–	1¾
Ovaries (both) ¼ to	–	½
Pancreas	–	3
Salivary Glands (both sides) 1½ to	–	2
Stomach	–	7
Spinal Cord, divested of its nerves and membranes	–	1½
Spleen	–	7
Suprarenal Capsules (both), ⅛ to	–	¼
Testicles (both) 1½ to	–	2
Thyroid body and remains of Thymus gland	–	¾
Tongue and Hyoid bone	–	3
Uterus (virgin) ½ to	–	¾

MEASURES OF LENGTH (*Average*).

	ft.	in.
Appendix vermiformis 3 to	–	6
Bronchus, right	–	1½
" left	–	2½
Cæcum	–	2½
Duct, common bile	–	3
" " ejaculatory, ¾ to	–	1
" of Cowper's gland	–	1¼
" hepatic	–	2
" nasal	–	–¾
" parotid	–	2½
" sub-maxillary	–	2
Epididymis	–	1¾
" unraveled	20	–
Eustachian tube	–	1½
Fallopian tube	–	3½
Intestine, large	5 to 6	–
" small	20	–
Ligament, round, of uterus	–	4½

	ft.	in.
Ligament of ovary	–	1½
Meatus auditorius externus	–	1¼
Medulla oblongata	–	1¼
Œsophagus	–	10
Pancreas	–	7
Pharynx	–	4½
Rectum	–	8
Spinal cord	1	5
Tubulus seminiferus	2	3
Urethra, male	–	8
" female	–	1½
Ureter	1	4
Vagina 4 to	–	6
Vas deferens	2	–
Vesicula seminalis	–	2
" " unraveled, 4 to	–	6
Vocal cord	–	–½

SIZES OF VARIOUS HISTOLOGICAL ELEMENTS AND TISSUES.

Average size in fractions of an inch.

Air-cells, $\frac{1}{70}$ to $\frac{1}{50}$.
Blood-cells (red), $\frac{1}{3200}$ (breadth).
" " $\frac{1}{10000}$ (thickness).
" (colorless), $\frac{1}{2500}$.
Canaliculus of bone, $\frac{1}{7000}$ (width).
Capillary blood-vessels, $\frac{1}{3000}$ (lung) to $\frac{1}{1200}$ (bone).
Cartilage-cells (nuclei of), $\frac{1}{3000}$.
Chyle-molecules, $\frac{1}{30000}$.
Cilia, $\frac{1}{5000}$ to $\frac{1}{2500}$ (length).
Cones of retina (at yellow spot), $\frac{1}{12000}$ to $\frac{1}{10000}$ (width).
Connective-tissue fibrils, $\frac{1}{50000}$ to $\frac{1}{15000}$ (width).
Dentine-tubules, $\frac{1}{4500}$ (width).
Enamel-fibres, $\frac{1}{5000}$ (width).
End-bulbs, $\frac{1}{600}$.
Epithelium
  columnar (intestine), $\frac{1}{2000}$ (length).
  spheroidal (hepatic), $\frac{1}{1000}$ to $\frac{1}{800}$.
  squamous (peritoneum) $\frac{1}{10000}$ (width).
  squamous (mouth), $\frac{1}{600}$ (width).
  " (skin), $\frac{1}{800}$ (width).
Elastic (yel.) fibres, $\frac{1}{24000}$ to $\frac{1}{4000}$ (wide).
Fat-cells, $\frac{1}{500}$ to $\frac{1}{400}$.
Germinal vesicle, $\frac{1}{720}$.
" spot, $\frac{1}{3000}$.
Glands
  gastric, $\frac{1}{60}$ to $\frac{1}{20}$ (length).
  " $\frac{1}{500}$ to $\frac{1}{360}$ (width).
  Lieberkuhn's (small intestines), $\frac{1}{360}$ to $\frac{1}{250}$ (length).
  Lieberkuhn's (small intestine), $\frac{1}{600}$ (width).
  Peyer's (follicles), $\frac{1}{24}$ to $\frac{1}{12}$.
  Sweat, $\frac{1}{70}$ (width).
  " in axilla, $\frac{1}{36}$ to $\frac{1}{8}$ (width).
Haversian canals, $\frac{1}{1000}$ to $\frac{1}{200}$ (width).
Lacunæ (bone), $\frac{1}{1800}$ (length).
" " $\frac{1}{3600}$ (width).
Macula lutea, $\frac{1}{24}$.
Malpighian bodies (kidney), $\frac{1}{120}$.
" corpuscles (spleen), $\frac{1}{60}$ to $\frac{1}{30}$.
Muscle (striated), $\frac{1}{500}$ to $\frac{1}{400}$ (width).
Muscle-cell (plain), $\frac{1}{600}$ to $\frac{1}{300}$ length).
Muscle-cell (plain), $\frac{1}{4500}$ to $\frac{1}{3500}$ (width).
Nerve-corpuscles (brain), $\frac{1}{3000}$ to $\frac{1}{300}$.
Nerve-fibres (medullated) $\frac{1}{12000}$ to $\frac{1}{1500}$ (width).
Nerve-fibres (non-medullated) $\frac{1}{8000}$ to $\frac{1}{5000}$ (width).
Ovum, $\frac{1}{120}$.
Pacinian bodies, $\frac{1}{15}$ to $\frac{1}{10}$ (length).
" " $\frac{1}{25}$ to $\frac{1}{20}$ (width).
Papillæ of skin (palm), $\frac{1}{200}$ to $\frac{1}{100}$ (length).
" " (face), $\frac{1}{800}$ to $\frac{1}{500}$.
" tongue (circumvallate), $\frac{1}{20}$ to $\frac{1}{12}$ (width).
" " (fungiform), $\frac{1}{35}$ to $\frac{1}{25}$ (width).
" " (filiform), $\frac{1}{10}$ (length).
Pigment-cells of choroid (hexagonal), $\frac{1}{1000}$.
Pigment-granules, $\frac{1}{20000}$.
Spermatozoon, $\frac{1}{600}$ to $\frac{1}{500}$ (length).
" head, $\frac{1}{5000}$ "
" " $\frac{1}{10000}$ (width).
Touch-corpuscle, $\frac{1}{300}$ (length).
Tubuli seminiferi, $\frac{1}{200}$ to $\frac{1}{100}$ (width).
Tubuli uriniferi, $\frac{1}{500}$.
Villi, $\frac{1}{50}$ to $\frac{1}{8}$ (length).
" $\frac{1}{250}$ to $\frac{1}{70}$ (width).

SPECIFIC GRAVITY OF VARIOUS FLUIDS AND TISSUES.

(*Water* = 1·000.)

Adipose tissue	0·932
Bile	1·020
Blood	1·055
" corpuscles (red)	1·088
Body (entire)	1·065
Bone	1·870 to 1·970
Brain	1·036
" grey matter	1·034
" white	1·040
Cartilage	1·150
Cerebro-spinal fluid	1·006
Chyle	1·024
Gastric juice	1·0023
Intestinal juice	1.011
Kidney	1·052
Liquor amnii	1·008
Liver	1.055
Lymph	1·020
Lungs	
when fully distended	0·126
ordinary condition, post mortem	0·345 to 0.746
when deprived of air	1·056
Muscle	1·020
Milk	1·030
Pancreatic juice	1·012
Saliva	1·006
Serum	1·026
Spleen	1.060
Sweat	1·004
Urine	1·020

TABLE SHOWING THE PERCENTAGE COMPOSITION OF VARIOUS ARTICLES OF FOOD. (LETHEBY.)

	Water.	Albumin.	Starch.	Sugar.	Fat.	Salts.
Bread	37	8·1	47·4	3·6	1·6	2·3
Oatmeal	15	12·6	58·4	5·4	5·6	3·
Indian corn meal	14	11·1	64·7	0·4	8·1	1·7
Rice	13	6·3	79·1	0·4	0·7	0·5
Arrowroot	18	—	82·	—	—	—
Potatoes	75	2·1	18·8	3·2	0·2	0·7
Carrots	83	1·3	8·4	6·1	0·2	1·0
Turnips	91	1·2	5·1	2·1	—	0·6
Sugar	5	—	—	95·0	—	—
Treacle	23	—	—	77·0	—	—
Milk	86	4·1	—	5·2	3·9	0·8
Cream	66	2·7	—	2·8	26·7	1·8
Cheddar cheese	36	28·4	—	—	31·1	4·5
Lean beef	72	19·3	—	—	3·6	5·1
Fat beef	51	14·8	—	—	29·8	4·4
Lean mutton	72	18·3	—	—	4·9	4·8
Fat mutton	53	12·4	—	—	31·1	3·5
Veal	63	16·5	—	—	15·8	4·7
Fat pork	39	9·8	—	—	48·9	2·3
Poultry	74	21·0	—	—	3·8	1·2
White fish	78	18·1	—	-	2·9	1·0
Eels	75	9·9	—	—	13·8	1·3
Salmon	77	16·1	—	—	5·5	1·4
White of egg	78	20·4	—	—	—	1·6
Yelk of egg	52	16·0	—	—	30·7	1·3
Butter and Fat	15	—	—	—	83·0	2·0
Beer and porter	91	0·1	—	8·7	—	0·2

CLASSIFICATION OF THE ANIMAL KINGDOM.

Vertebrata.

MAMMALIA	*Typical Examples.*
Primates	Man.
"	Ape, baboon.
Chiroptera	Bat, flying fox.
Insectivora	Mole, hedgehog.
Carnivora	Lion, dog, bear, seal.
Proboscidea	Elephant.
Hyracoidea	Hyrax
Ungulata:	
Perissodactyla	Tapir, rhinoceros, horse.
Artiodactyla	Hippopotamus, pig, camel, chevrotain, deer, ox, sheep, goat, giraffe.
Sirenia	Dugong, manatee.
Cetacea	Whale, porpoise, narwhal.
Rodentia	Hare, porcupine, guinea pig, rat, beaver, squirrel, dormouse.
Edentata	Armadillo, pangolin, true anteater, Cape anteater, sloth.
Marsupiata	Opossum, bandicoot, Thylacinus, phalanger, wombat, kangaroo.
Monotremata	Ornithorhynchus, or duck-billed platypus, Echidna or spiny anteater.
BIRDS	
CARINATÆ	
Raptores (*Birds of Prey*)	Vulture, hawk, owl.
Scansores (*Climbing Birds*)	Woodpecker, parrot.
Passeres (*Perching Birds*)	Crow, finch, swallow.
Rasores (*Scratching Birds*)	Fowl, pheasant, grouse.
Grallatores (*Wading Birds*)	Heron, stork, snipe, crane.
Natatores (*Swimming Birds*)	Penguin, duck, pelican, gull.
RATITÆ	
Cursores (*Running Birds*)	Ostrich, emeu, apteryx.
REPTILES	
Crocodilia	Crocodile, alligator,
Lacertilia	Iguana, chameleon, gecko, lizard, slow-worm, flying dragon.
Chelonia	Tortoise, turtle
Ophidia	Snake, viper.
AMPHIBIA	
Anura	Frog, toad.
Urodela	Newt, salamander.
FISH	
Dipnoi	Lepidosiren.
Teleostei	Perch, mackerel, cod, herring.
Placoidei	Shark, ray.
Ganoidei	Sturgeon, bony pike.
Cyclostomi	Lamprey, hag.
Leptocardii	Amphioxus lanceolatus.

CLASSIFICATION OF THE ANIMAL KINGDOM.

Invertebrata.

	Typical Examples.
MOLLUSCA	
Cephalopoda	Octopus, argonaut, squid, cuttle-fish, nautilus.
Pteropoda	Clio, Cleodora.
Gasteropoda:	
Pulmonigasteropoda	Snail, slug.
Branchiogasteropoda	Whelk, limpet, periwinkle.
Lamellibranchiata	Oyster, mussel, cockle.
Brachiopoda	Terebratula, Lingula.
Tunicata, or Ascidioidea	Salpa, Pyrosoma.
Bryozoa or Polyzoa	Sea mat.
ARTHROPODA	
Insecta	Beetle, bee, ant, locust, grasshopper, cockroach, earwig, moth, butterfly, fly, flea, bug.
Arachnida	Scorpion, spider, mite.
Myriopoda	Centipede, millipede.
Crustacea	Crab, lobster, crayfish, prawn, barnacle.
Annulata	Sea-mouse, leech, earthworm.
Scolecida	Hair-worm, thread-worm, round-worm, fluke, tape-worm, guinea-worm.
Echinodermata	Sea-cucumber, sea-urchin, star-fish, sand-star, feather-star.
CŒLENTERATA	
Ctenophora	Beroe.
Anthozoa	Sea anemone, coral, sea-pen.
Hydrozoa	Hydra, Sertularia, Velella, Portuguese man-of-war.
Spongida	Sponges.
PROTOZOA	
Rhizopoda	Foraminifera, Amœba.
Infusoria	Paramœcium, Vorticella.

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